ASTRONOMY

February 1988
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## Secrets of the Supernova

## Build a Binocular Holder

## The Structure of the Universe

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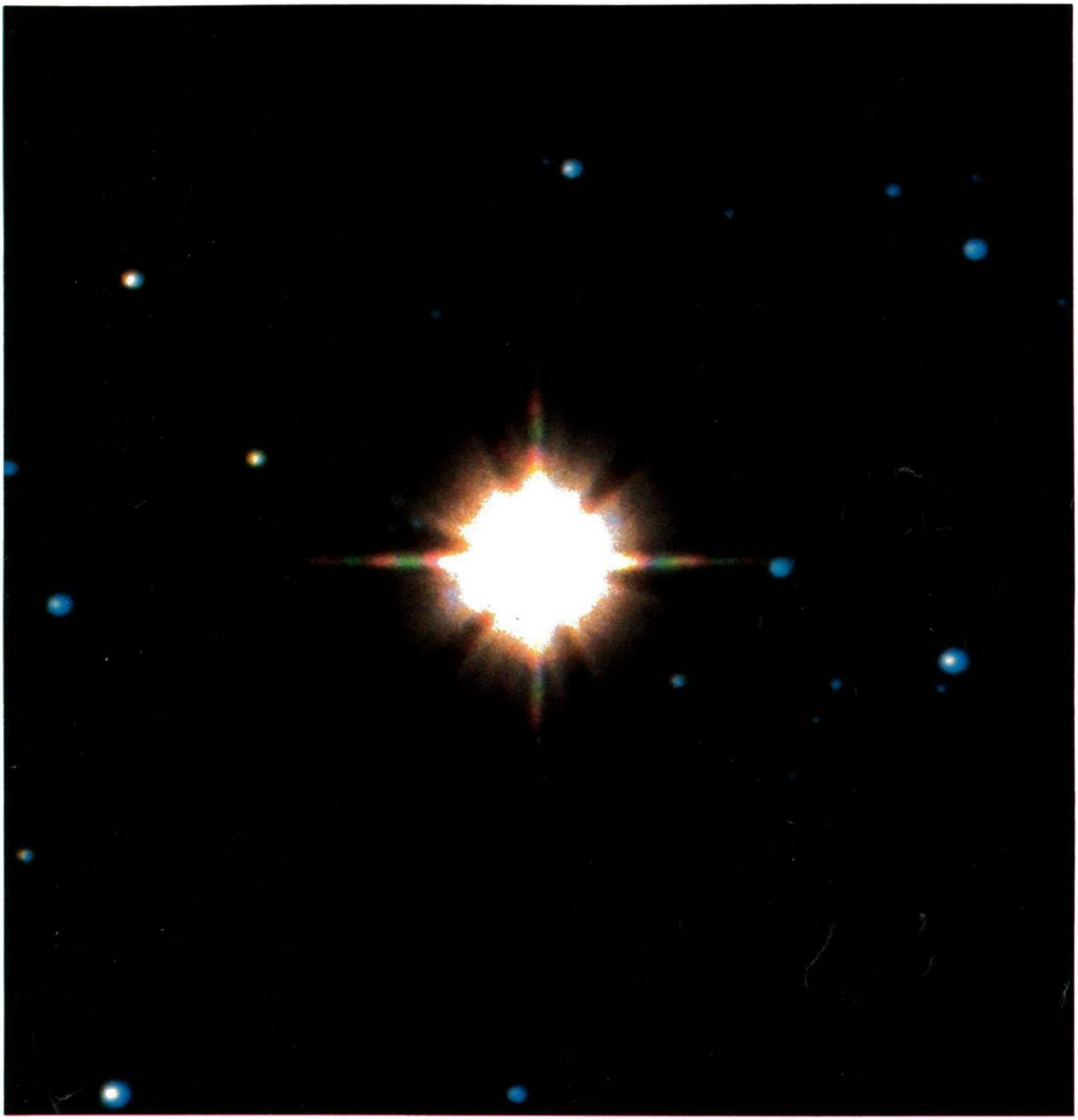
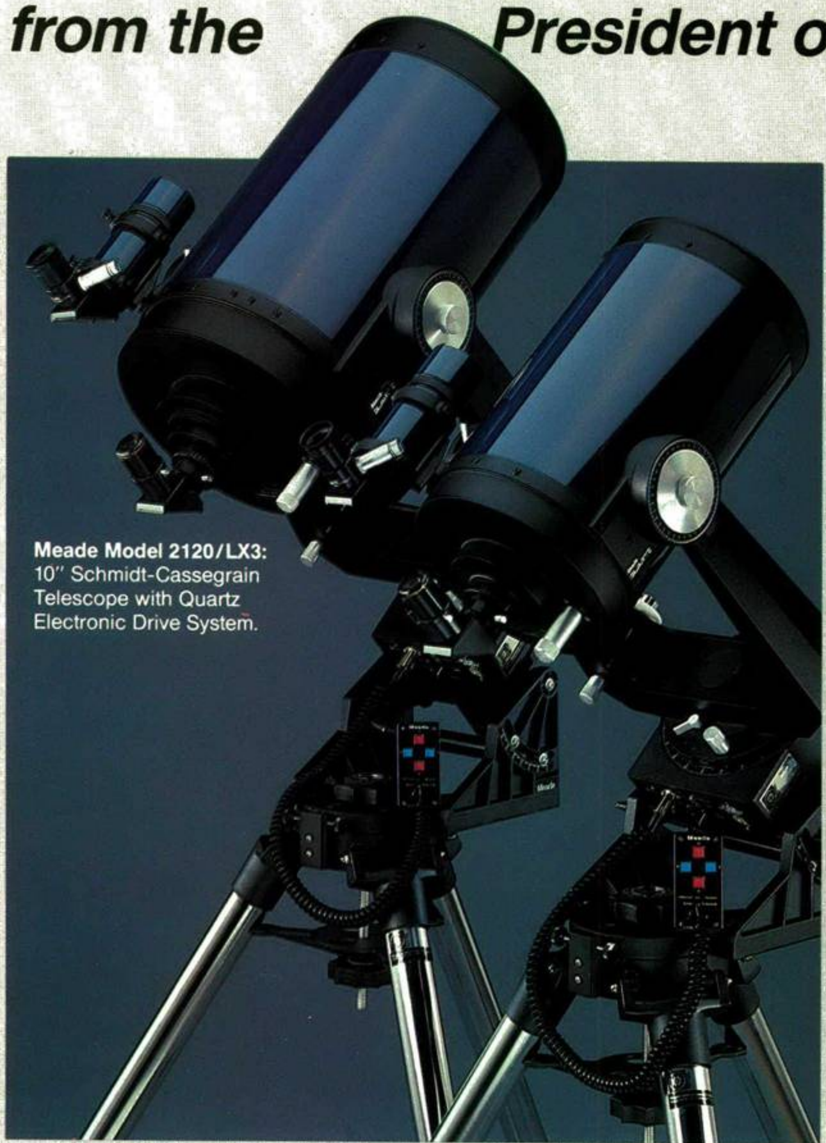


## Supernova 1987A: End of a Massive Star

# A Special Extended Offer to Meade Customers from the President of Meade Instruments:



**Meade Model 2120/LX3:**
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**The Meade 10″ Model 2120/LX3** *(left)* collects **56%** more light than an 8″ Schmidt-Cassegrain. (Meade 8″ Model 2080/LX3 shown at right for comparison.)

In October, 1987, we announced a special limited-time offer for Meade 10″ Model 2120/LX3 Schmidt-Cassegrains at the unheard of price of $1799. We felt at that time that at a price of $1799, we would be able to clear our stock of 2120/LX3's by December 31, 1987.

In fact, however, the response from serious amateur astronomers throughout the United States was so overwhelming that our entire stock was depleted within 9 days of the original announcement.

With the vastly successful introduction of the 10″ Model 2120/LX5 in 1987, we frankly had no plans to continue production of its predecessor, the 2120/LX3. At the same time, we well realize that the non-availability of 2120/LX3's in November and December, 1987, disappointed many loyal Meade customers.

In order to amend what was clearly a difficult situation for our customers, we are pleased to announce that **Meade 10″ Model 2120/LX3's will continue to be made available at the special price of $1799 for a limited additional time, and we pledge to manufacture as many brand-new 2120/LX3's as are required to meet the demand.**

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John C. Diebel, President
Meade Instruments Corporation

Each 2120/LX3 includes the #36 Electronic Drive Corrector/Hand Controller, shown plugged into the 2120/LX3 power panel.

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*This special offer on the Meade Model 2120/LX3 is available only at participating Meade dealers.*

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**SPECIFICATIONS:**

**Meade DS-10: 10″ f/4.5 Reflecting Telescope** — Includes null-figured, diffraction-limited Pyrex parabolic primary mirror and matching (2.60″ M.A.) 1/10-wave-flat elliptical secondary; #67 rack-and-pinion focuser; MA 25mm (46X) coated eyepiece; Sonotube 12″ I.D. x 46″ long, sealed and attractively Zolatone coated; all-metal, precision-machined equatorial mount, with ultrasmooth Nylon bearings and 1″ solid steel shafts; low-profile pier and tripod legs. **$785** through 3/31/88.

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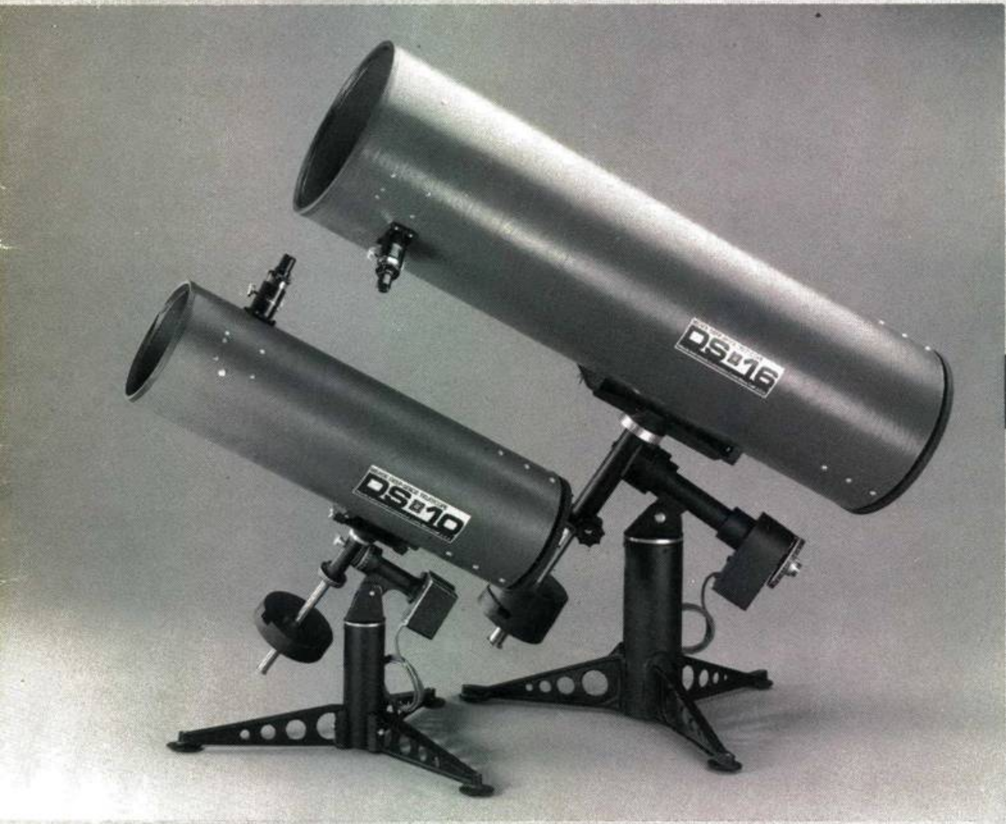

**Meade DS-10 and DS-16,** shown with optional motor drives, setting circles, giant focusers.

**Meade DS-16 Astrophotos:**
*(top)* Southern region of the Andromeda Galaxy (M31); *(lower)* The Horsehead Nebula. Both photos by Paul Roques.

**Dealer Locations and Assistance**

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# ASTRONOMY

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**Cover:** The explosion of supernova 1987A last February presented astronomers with their best view ever of a star's death. The blast confirmed many aspects of supernova theory and also provided theorists with new insights into how stars end their lives. University of Toronto photo. These pages: A thousand years from now the debris ejected by supernova 1987A may look like this supernova remnant. Photo of Crab Nebula taken with the 200-inch Hale telescope, copyright © 1959 by Palomar Observatory.

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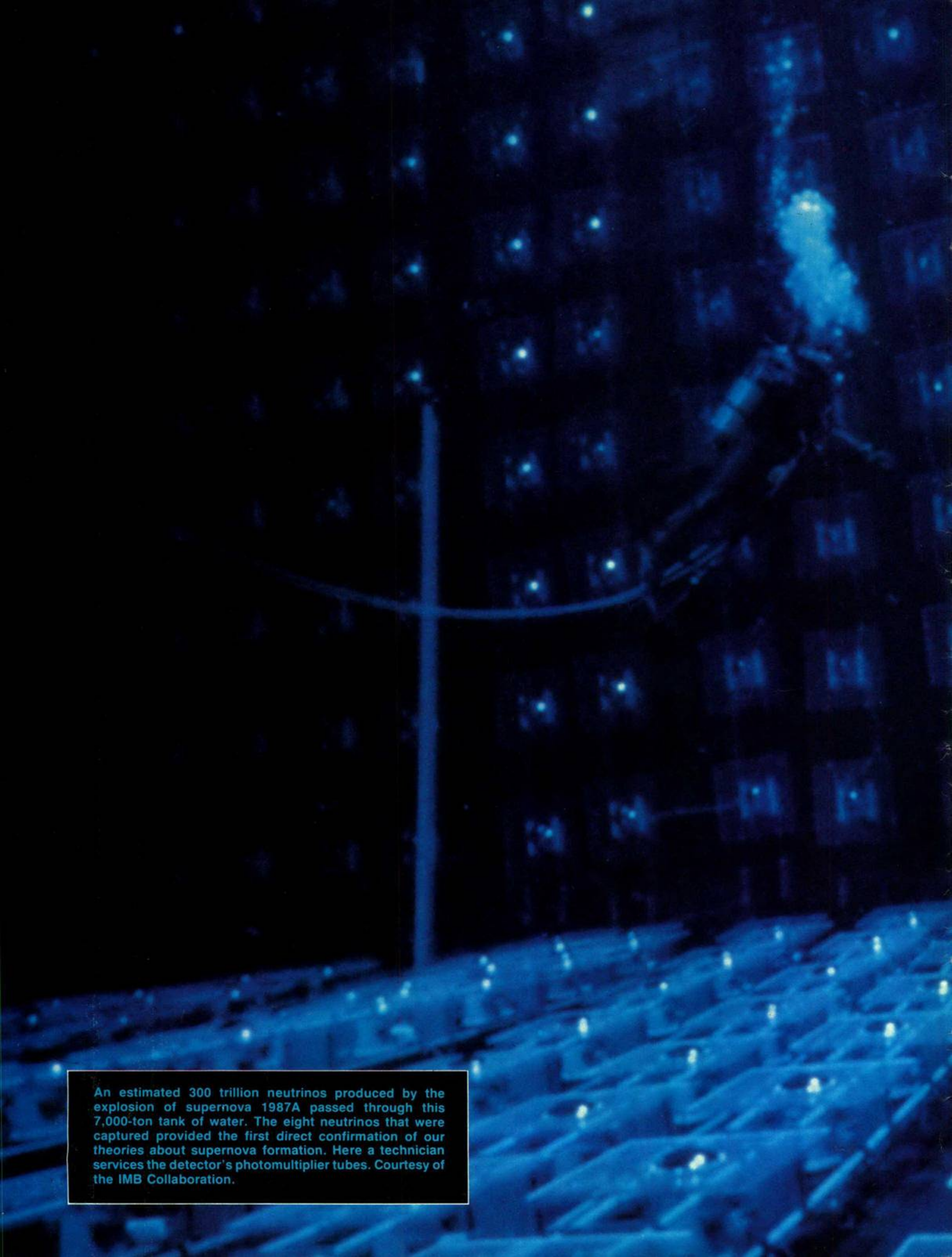


An estimated 300 trillion neutrinos produced by the explosion of supernova 1987A passed through this 7,000-ton tank of water. The eight neutrinos that were captured provided the first direct confirmation of our theories about supernova formation. Here a technician services the detector's photomultiplier tubes. Courtesy of the IMB Collaboration.

# Insight into Star Death

**Observations of supernova 1987A have taught us how massive stars die.**

by Richard Talcott

Nineteen neutrinos, formed in the center of a supernova, became a theorist's dream. They came straight from the heart of supernova 1987A and landed in two big underground tanks of water. Suddenly a new chapter in observational astronomy opened as these two "neutrino telescopes" gave astronomers their first look ever into the core of a supernova explosion.

But the theorists' dream almost turned into a nightmare. Observations of the presupernova star showed conclusively that the star was a blue supergiant, but theorists have long believed only red supergiant stars could explode as supernovae.

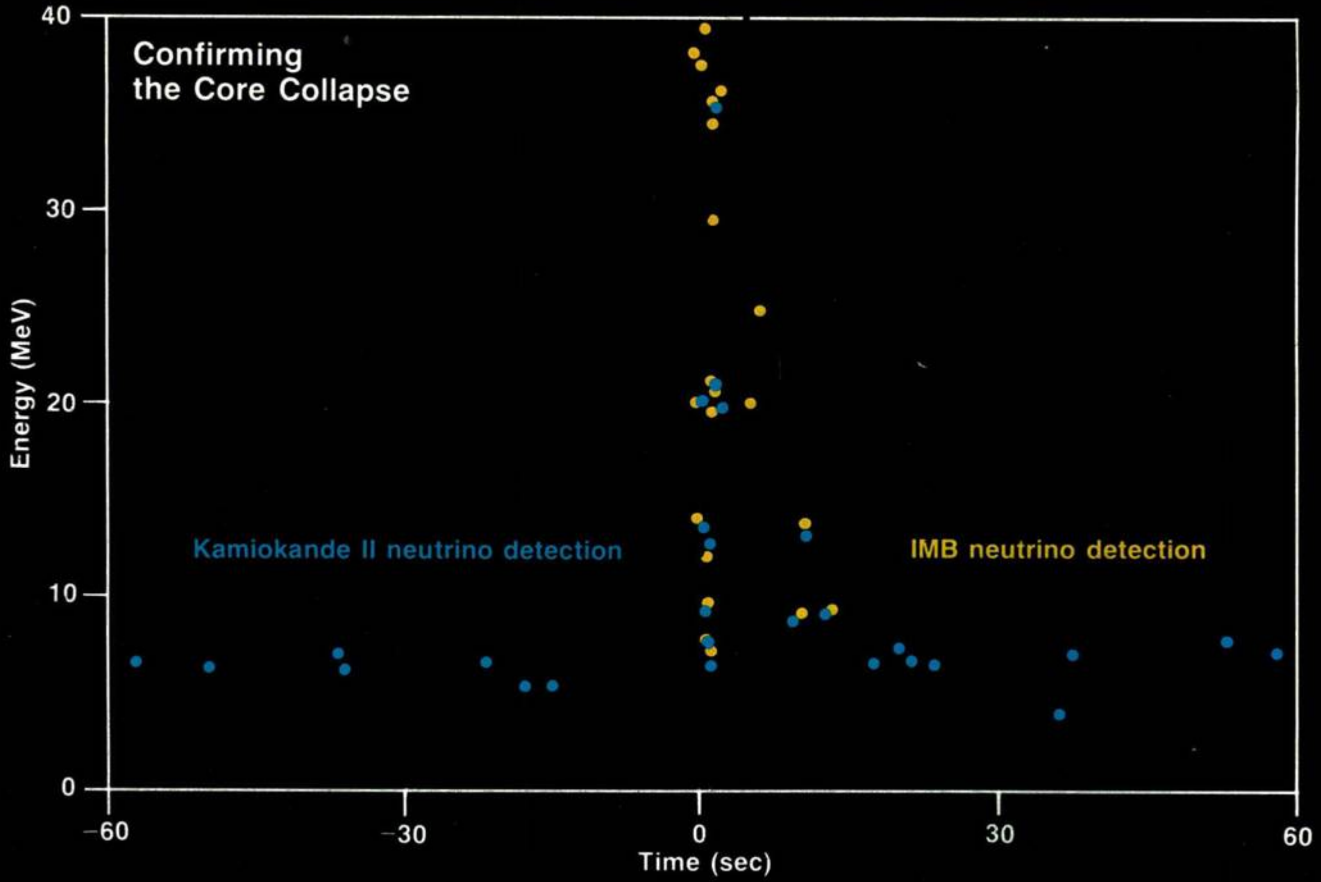
Do astronomers understand supernovae better now than when supernova 1987A exploded in the Large Magellanic Cloud (LMC) one year ago? Yes. The observations of neutrinos spectacularly confirmed a vital aspect of supernova theory. But the observed differences between 1987A and other supernovae have illuminated and advanced our perception of how supernovae form. By working together, observers and theorists are continuing to hone their ideas about how massive stars die and how the subsequent supernovae behave.

### Stellar Beginnings

Only a tiny fraction of all stars ends life as spectacularly as did Sanduleak −69°202 — the star that became supernova 1987A. Most stars live a quiet life and die a quiet death. The fate of an individual star depends on the properties the star was born with and, most importantly, on the star's mass.

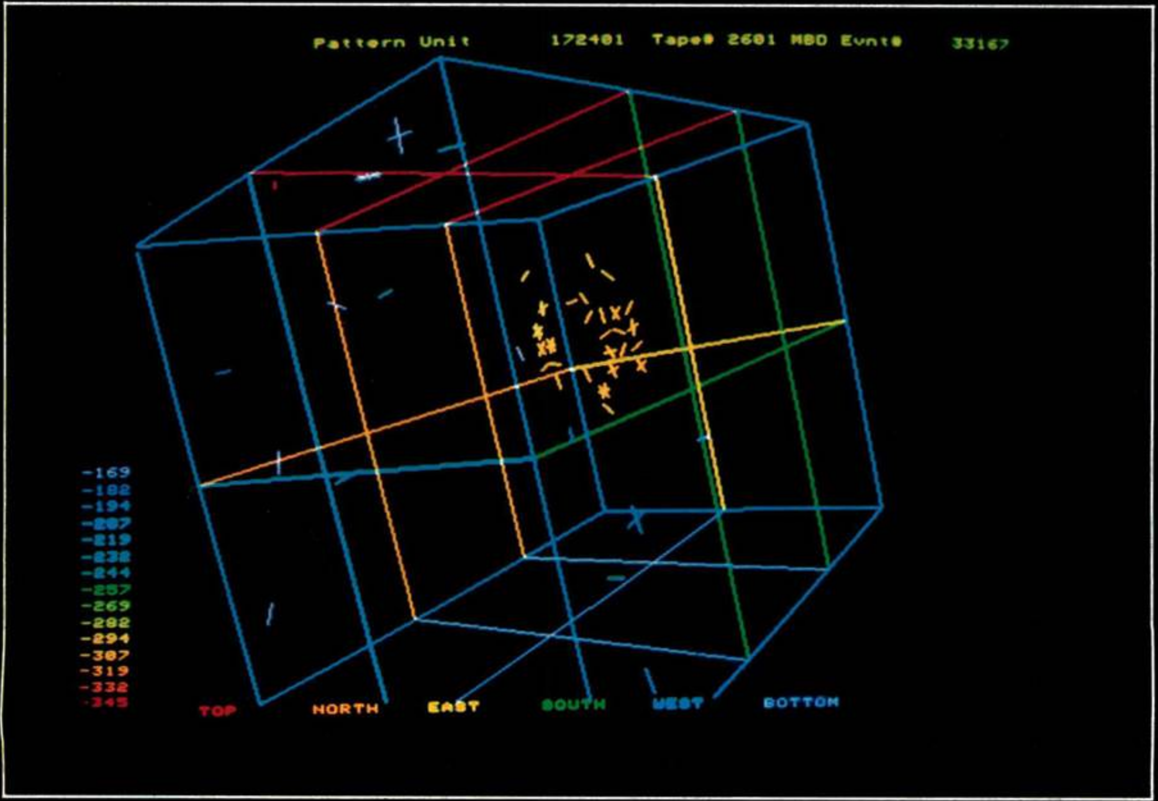
Sanduleak −69°202 began the long journey to becoming a supernova several million years ago. Humans were not then able to view such distant objects, but modern observational astronomers have confirmed the basic theory of how stars form.

According to theory, a star starts out as a small condensation, or density enhancement, inside an interstellar cloud of gas and dust. Such clouds are common in the Large Magellanic Cloud, and there are several regions of



Above: Nineteen neutrinos expelled by supernova 1987A largely confirmed existing theories about how supernovae explode. The vertical line represents the arrival time of the first supernova neutrino; all of the remaining neutrinos arrived within 12.5 seconds. (The low-energy neutrinos are background events unrelated to the supernova.) The energy and arrival times of the neutrinos allow astrophysicists to model the conditions in the stellar core at the time of collapse.

Below: At 7:35:41 universal time on February 23, 1987, one of the nineteen neutrinos that we captured from supernova 1987A struck a proton in the Irvine-Michigan-Brookhaven (IMB) detector. The interaction produced a neutron and a positron, and the positron in turn produced faint flashes of light. The yellow crosses in this computer-generated image indicate which of the 2,048 photomultiplier tubes in the detector recorded the light signals. Courtesy of the IMB Collaboration.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active star formation in this neighboring galaxy. Because the condensation is slightly more dense than its immediate surroundings, it gravitationally attracts nearby matter. This increases the mass of the condensation, which in turn increases the gravitational attraction of the condensation, and the process continues until a star-sized object is formed. Meanwhile, other regions of the cloud also fragment into star-sized objects.

The initial cloud is composed mostly of hydrogen and helium, while heavier elements account for a small percentage of the cloud's make-up. The heavy elements originated in the cores of earlier generations of massive stars. These stars subsequently exploded as supernovae, expelling the heavy elements into the interstellar medium. The abundance of heavy elements in the LMC is only about one quarter of that in the Milky Way Galaxy, so stars in the LMC have smaller amounts of heavy elements than their Milky Way counterparts do.

Mathematically, astronomers know that once the condensation process begins, it is self-perpetuating — the major stumbling block to creating stars is forming these condensations in the first place, because some force must act on the cloud to trigger the initial condensations.

One way condensations can form is through instabilities created by the collision of two interstellar clouds. A cloud can also start condensing as a result of a nearby supernova. The shock wave that creates the supernova continues to propagate through space, where the shock wave compresses the surrounding interstellar material and may initiate star formation. In this way the death of one star can literally trigger the formation of a new generation of stars.

The stellar embryo, or protostar, contracts under the influence of gravity and releases heat in the process. Eventually the protostar becomes dense enough that the generated heat cannot escape freely and is instead partially trapped inside the growing protostar. The internal heat produces pressure, and that pressure counteracts the weight of the overlying material.

This state of equilibrium does not mean the protostar is stable, however. Because the pressure derives from the heat generated by gravitational contraction, the state of equilibrium can only be maintained by further contraction. The contraction continues to heat the star's interior until the internal temperature is high enough to sustain nuclear reactions. The protostar becomes a star when the heat generated by the nuclear reactions balances the energy emitted by the star and the interior pressure completely supports the overlying material from further gravitational contraction.

Astrophysicists believe the life history of every star is marked by the continuing struggle between the forces of gravity and internal pressure. Gravity tries to squeeze the star into a smaller volume, while pressure attempts to expand the star. Over most of a star's lifetime the two forces balance each other, and the star remains stable. Whenever one force dominates the other, however, the star must undergo a significant structural change.

The total mass of the protostar determines how long the contraction phase will last: the higher the mass, the faster the process. For this reason, high-mass stars like Sanduleak −69°202 will be fully formed while smaller protostars are still condensing from the gas and dust in the cloud.

The onset of nuclear reactions in the core of a star begins the main-sequence phase — the longest period in the star's life. The star generates energy by fusing, or "burning," the hydrogen in its core into helium. Each nuclear fusion converts four hydrogen atoms into one helium atom and releases a relatively small amount of energy. A star like the Sun shines brightly because it burns hundreds of millions of tons of hydrogen every second.

Just as massive protostars reach the main sequence faster than their less massive cousins, massive stars also spend a shorter length of time on the main sequence than less massive stars do. Massive stars generate much more energy than lower mass stars because their interiors are much hotter and the nuclear reactions proceed at a faster rate. Thus, massive stars use up their fuel at a much faster rate. A star like the Sun will stay on the main sequence for about 10 billion years, and a star one tenth the Sun's size can survive for 1 trillion years. A star as massive as Sanduleak −69°202, which contained about twenty solar masses before it exploded, cannot survive longer than several million years before its source of fuel is exhausted.

**The life history of every star is marked by the continuing struggle between gravity and internal pressure.**

### Beyond the Main Sequence

Once a massive star exhausts the hydrogen fuel in its core, the star accelerates down the road toward a supernova explosion. No longer able to supply the pressure needed to counteract the weight of the overlying material, the star's core begins to contract again. The delicate balance between gravity and internal pressure is tipped once more in favor of gravitation.

Just as in the protostar stage, the contraction heats the star's interior. The extra heat is absorbed by the star's hydrogen envelope, which forces the envelope to expand greatly. The expansion cools the surface layers of the star and causes the bloated star to shine red. The star becomes a red giant or a red supergiant, depending on how much mass the star has.

Meanwhile, the heat generated by the contraction raises the temperature of the hydrogen immediately surrounding the core and causes nuclear reactions there to speed up. The star is now not only larger and redder but more luminous.

Astronomers know the core of the star continues to contract until its temperature reaches 100 million kelvins — hot enough for helium to undergo fusion. Each reaction converts three helium nuclei into one carbon nucleus and releases energy in the process. Later some of the carbon fuses with helium to form oxygen nuclei. The energy released expands the core of the star and causes the outer envelope to shrink, which raises the star's surface temperature.

The helium-burning phase of a star's life is much shorter than the hydrogen-burning phase because the core is much hotter and the reactions occur much faster. When the helium is exhausted, the same situation prevails as at the end of the star's main-sequence life: no energy is being generated in the core to counteract the inward pull of gravity.

Whether a star becomes a supernova or not depends on the star's initial mass. For a star the size of the Sun the end is rather tranquil. After the helium in the core has been depleted, the core contracts and heats up once again. However, the temperature never rises high enough to initiate another round of nuclear fusion. Eventually the core becomes so dense that the free electrons become "degenerate" — squeezed so tightly together that they exert a significant pressure by themselves — and resist further compression.

Thus, low-mass stars become white dwarfs. These have the mass of a star but are compressed into a sphere about the size of Earth. The density is enormous: one cubic centimeter of white dwarf material would weigh a ton or more. Without any further source of internal energy the white dwarf will slowly and forever cool like the dying embers of a fire.

**Stars more than eight times the mass of the Sun must end their lives as supernovae.**

The Indian-American astrophysicist Subrahmanyan Chandrasekhar proved more than fifty years ago that no white dwarf can have a mass greater than 1.4 solar masses. Chandrasekhar realized that a more massive object would collapse beyond the white dwarf stage, because the force of gravity is stronger than the pressure supplied by the degenerate electrons. To end life as a white dwarf, a star larger than 1.4 solar masses must eject this excess mass, probably by a strong stellar wind during the red giant or supergiant phase or during a planetary nebula phase.

### Layered like an Onion

Stars initially more than eight times as massive as the Sun must end their lives as supernovae. Stars between about eight and eleven solar masses form an intermediate class and are theoretically the most difficult to model. Observations of supernova 1987A give astronomers their first close look at how a star larger than eleven solar masses explodes and therefore offer a superb test of how well theory agrees with reality.

Before it exploded, Sanduleak −69°202 had about twenty solar masses of material. In such high-mass stars, elements continue to fuse in the interior until the very core of the star consists of iron. The multitude of nuclear reactions that occurs before the star reaches this final configuration creates all the elements in the universe up to iron.

The first step on this path occurs when the contracting core of carbon and oxygen left over from the fusion of helium reaches a temperature around 600 million kelvins. New nuclear reactions then take place, forming neon and magnesium in the core. After each stage of burning is complete, the core contracts until the temperature rises high enough to initiate the next round of nuclear reactions. The sequence of reactions continues as the core's temperature rises to 1 billion to 3 billion kelvins. Neon burns next, then oxygen, and finally silicon burns into iron.

During its final moments of life the star has an onionlike structure. A core of iron is surrounded by a layer of silicon, which in turn is surrounded by layers of oxygen, carbon, helium, and finally hydrogen. Each layer contains lesser amounts of other elements created by additional nuclear reactions in the star's interior. The temperature in the star's interior is so high that nuclear reactions occur at the boundary between each of these layers. For example, helium still burns into carbon at the boundary of these two layers and deposits more carbon ashes on the layer below.

Because the temperature in the star's core keeps rising with each contraction, the rate of nuclear burning also increases. Sanduleak −69°202 took several million years to convert the initial hydrogen in its core into helium, but transforming helium into carbon only took around half a million years. The pace increased exponentially with each succeeding reaction. Carbon-burning lasted several hundred years, neon-burning was complete within a year or so, and the oxygen-burning took several months. The final stage in which silicon formed iron lasted only a couple of days.

Even at this advanced stage of evolution the bulk of Sanduleak −69°202 still consisted of hydrogen with a substantial proportion of helium. From these two elements, however, nuclear reactions formed several solar masses of heavier elements. When the star became a supernova, these elements were spewed into space, where they may one day be incorporated into a new generation of stars.

### Collapse!

Once a star begins fusing silicon into iron, the star's death is imminent. Iron has the most stable nucleus of any element; therefore fusing iron requires the input of energy and does not generate energy. There are no more nuclear reactions available to produce energy.

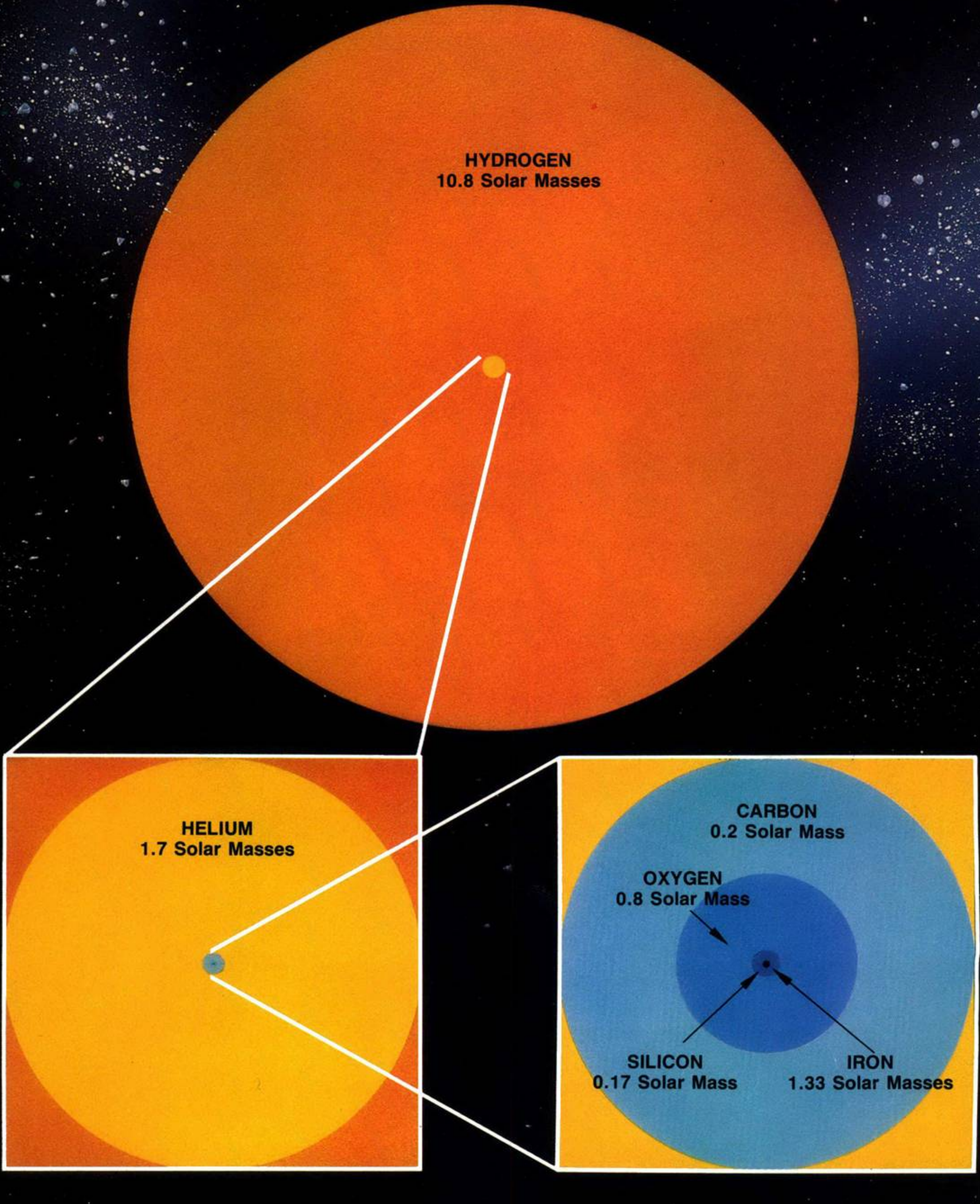
The iron core remains inert — like a white dwarf buried deep within the star. Unlike a white dwarf, the iron core cannot last. Silicon continues to burn in a shell surrounding the iron core, which adds to the growing mass of iron. Eventually the mass of the core reaches the Chandrasekhar limit, and the pressure provided by the degenerate electrons can no longer support the star. At this stage the core has a radius of a few thousand kilometers, a density of between 1 billion and 10 billion grams per cubic centimeter, and a temperature of several billion kelvins.

Without any other source of internal pressure the core begins to collapse. The collapse happens so rapidly that the outer regions of the star are at first totally unaffected by the catastrophe in the core. Although the collapse starts the supernova explosion that will ultimately destroy the star, the collapse is a phenomenon of the core only.

The speed of the collapse increases with time. As the densities rise, protons combine with electrons to produce neutrons and neutrinos in vast quantities. Under normal conditions a neutrino rarely interacts with matter. However, the conditions in the collapsing core are far from normal. Once the density of the infalling material reaches 100 billion grams per cubic centimeter, the average neutrino interacts with matter in the core before it can travel far enough to escape. Hence, even neutrinos are trapped inside the collapsing core.

The collapsing core separates into two distinct regions. Material in the inner region collapses with a velocity proportional to its radius, which means this part of the core collapses as a single unit. The two regions collapse separately because no disturbance in the inner region can travel fast enough to reach and thereby influ-

# A Star on the Brink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CARBON
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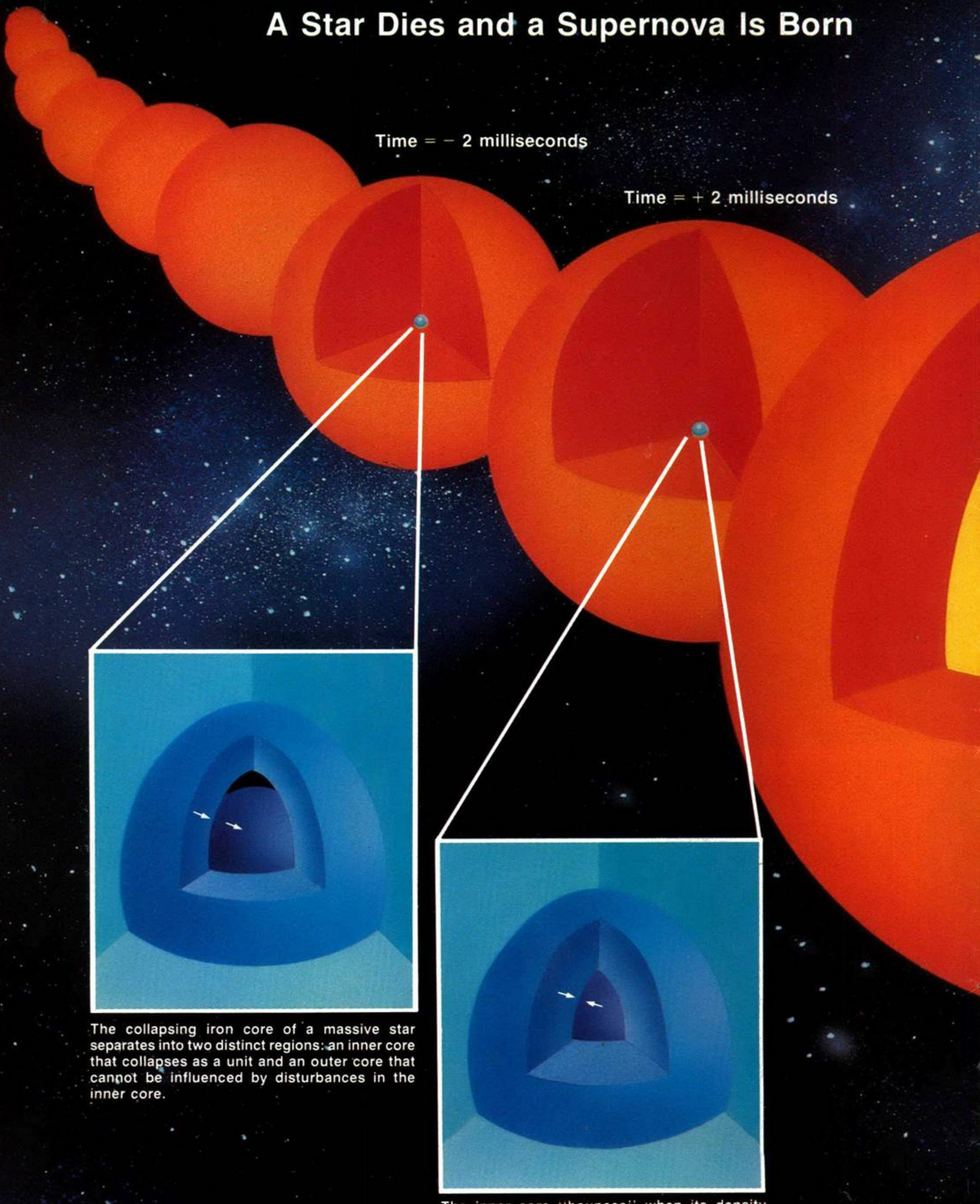
OXYGEN
0.8 Solar Mass
SILICON
0.17 Solar Mass
IRON
1.33 Solar Masses

At the end of its life a massive star resembles a gigantic onion — each layer in the onion is a shell of different nuclear reactions. Each layer also contains a mixture of many elements; the dominant element in each is labeled. The mass of each layer and the relative radii of the layers are based on models for a typical fifteen-solar-mass red supergiant. Illustration by Dick Scover.

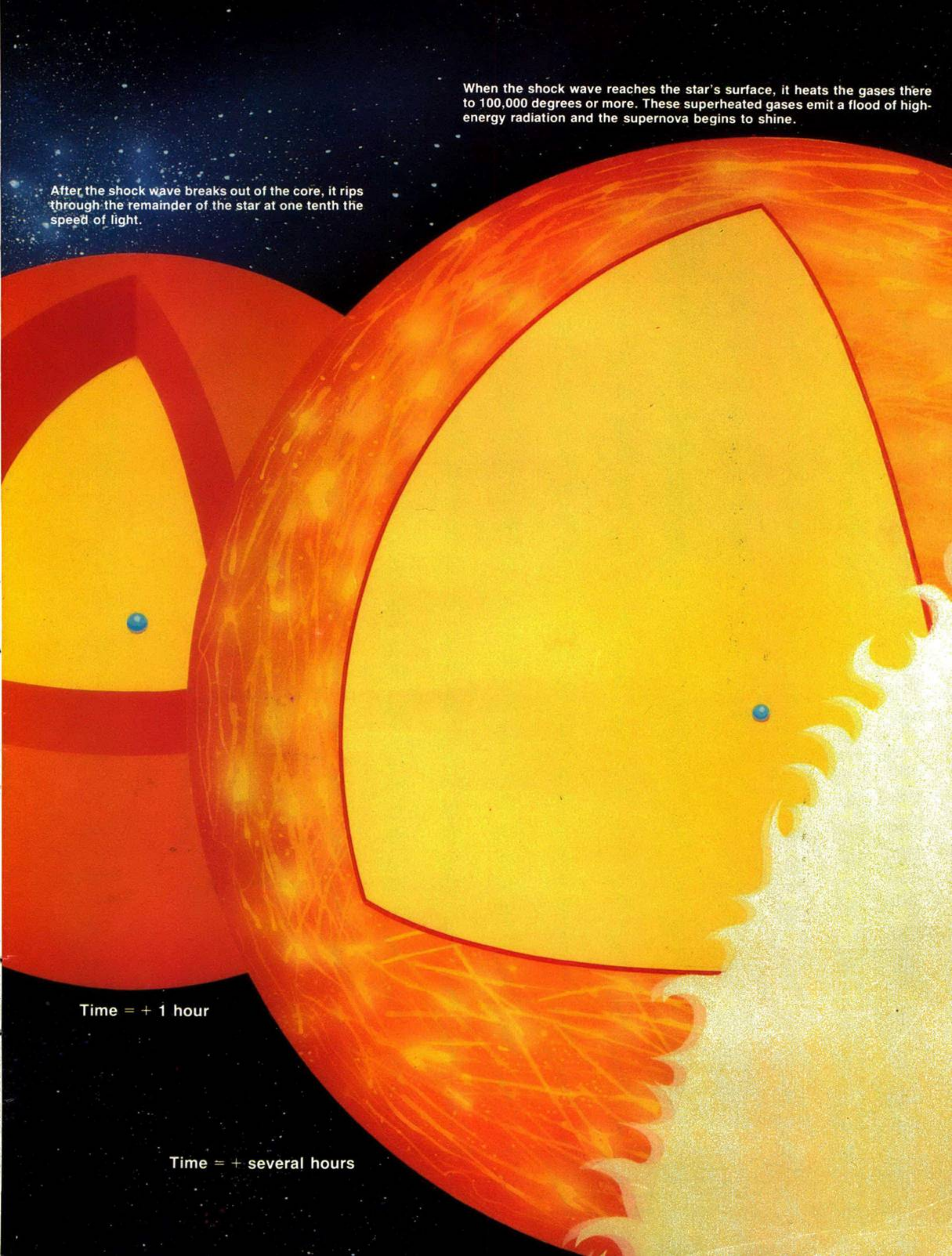
# A Star Dies and a Supernova Is Born



The collapsing iron core of a massive star separates into two distinct regions: an inner core that collapses as a unit and an outer core that cannot be influenced by disturbances in the inner core.

The inner core "bounces" when its density reaches that of an atomic nucleus and rebounds to collide with the still collapsing outer core. A violent shock wave forms at the collision site and the supernova explosion is born.

Illustration by Dick Scover



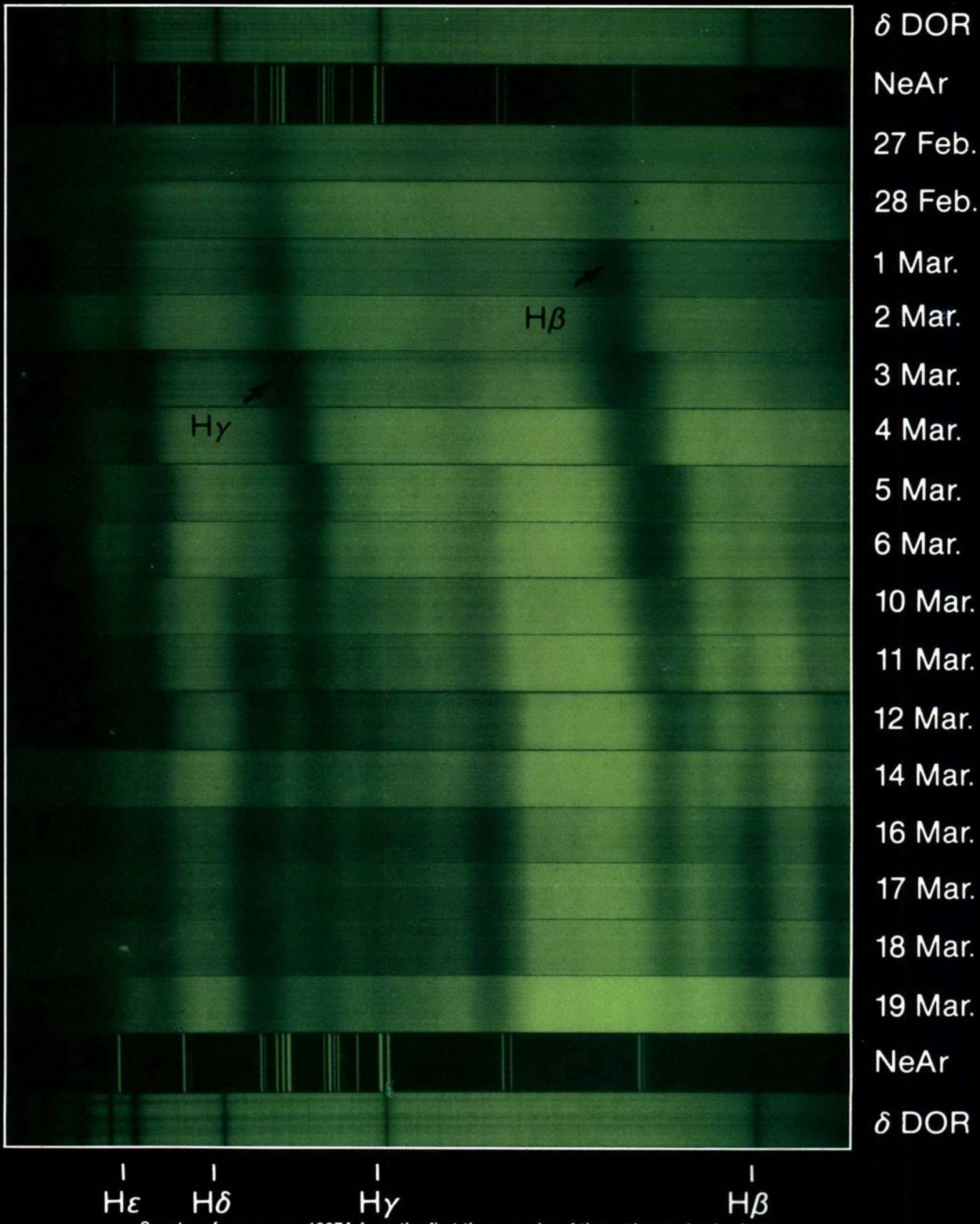
After the shock wave breaks out of the core, it rips through the remainder of the star at one tenth the speed of light.

Time = + 1 hour

When the shock wave reaches the star's surface, it heats the gases there to 100,000 degrees or more. These superheated gases emit a flood of high-energy radiation and the supernova begins to shine.

Time = + several hours

# The Expanding Supernova



Spectra of supernova 1987A from the first three weeks of the outburst clearly show the rapidly expanding shell of gas. The dominant hydrogen lines have much shorter wavelengths than they normally would have because the material is expanding rapidly — as fast as 18,300 kilometers per second on the day of discovery. As time passes, the spectral lines show smaller shifts because they originate from deeper layers, and those layers move outward more slowly. A neon-argon emission spectrum and an absorption spectrum from the star Delta Doradus are included for comparison. Courtesy Robert Garrison, University of Toronto.

ence the outer region. The maximum speed of collapse is about 70,000 kilometers per second — about one quarter of the speed of light — and occurs near the boundary between the two regions.

The collapse continues until the inner core reaches the density of an atomic nucleus, about 2 x $10^{14}$ grams per cubic centimeter. Then the core material suddenly stiffens. The momentum of the collapse continues to squeeze the core for a fraction of a thousandth of a second longer. According to theoreticians, the core reaches a maximum density of about 8 x $10^{14}$ grams per cubic centimeter and a maximum temperature of some 100 billion kelvins. Sanduleak −69°202 spent several million years evolving from a protostar to a star with an iron core, but the iron core collapsed within one one-hundredth of a second.

The inner core now rebounds as a unit. The outer core knows nothing about this, however, and continues collapsing. The two regions collide, generating a shock wave. The shock wave is the birth of the supernova explosion.

### Meanwhile, Back on Earth

As the shock wave moved out through the interior of Sanduleak −69°202, it quickly reached areas where the density fell below 100 billion grams per cubic centimeter. At this density level the neutrinos that had been trapped inside the collapsing core began to escape. The neutrinos then traveled at the speed of light through the rest of the star and out into space.

At 7:35:41 universal time (2:35:41 EST) on February 23, 1987, neutrino detectors in Ohio and Japan simultaneously recorded the burst of neutrinos from 1987A. The Kamiokande-II detector recorded eleven neutrino interactions in 12.5 seconds, the Irvine-Michigan-Brookhaven (IMB) detector eight neutrinos in 5.5 seconds.

The neutrinos offered the first direct confirmation of the astrophysical theory concerning core collapse and supernova production. More than twenty years ago astrophysicists predicted that enormous numbers of neutrinos would form in the core of a collapsing star. Unfortunately there were no observations to test the theory. Not until 1987A was there a supernova close enough to Earth for astronomers to observe a supernova's neutrinos.

Both detectors consist of huge tanks of extremely pure water located deep underground. The Kamiokande-II detector contains 2,140 tons of water and is located in a mine in Kamioka, Japan. The IMB detector contains 7,000 tons of water and is located in a Morton-Thiokol salt mine in Fairport Harbor, Ohio. The few thousand feet of earth above the detectors shields them from high-energy cosmic rays, which the detectors would also capture if they were located on Earth's surface.

The detectors were built by physicists looking for a different phenomenon. The grand unified theories that attempt to unify three of the four fundamental forces of nature predict that the proton is an unstable particle, and physicists have been looking in the tanks for a sign that protons do decay, though none has been detected yet. Luckily the huge tanks of water are also sensitive to high-energy neutrinos, which gave astronomers a fortuitous look into the core of supernova 1987A.

### Neutrinos Tell What Happened Inside

Astronomers were elated and many were surprised at how closely the neutrino observations agreed with theory. Theory predicts that the neutrinos are produced in the collapsing core of the star in just a few thousandths of a second. However, these neutrinos will escape from the supernova over a period of several seconds because the dense core is opaque to neutrinos at the time of neutrino formation. The Kamiokande-II experiment detected supernova neutrinos over a 12.5-second interval, while the IMB experiment captured neutrinos over a 5.5-second interval.

Supernova theory also predicts that approximately equal numbers of the six different varieties of neutrinos should be produced in the supernova. Most of the observed neutrinos were electron antineutrinos that interacted with a proton in the tank of water to form a neutron and a positron (a positively charged electron). The positrons produced a feeble flash of light that subsequently triggered some of the detector's photomultiplier tubes. The apparent absence of other types of neutrinos was expected: the protons in the water tank are over one hundred times more likely to capture an electron antineutrino than any other variety.

**Sanduleak −69°202 spent several million years forming an iron core, but the iron core collapsed within one one-hundredth of a second.**

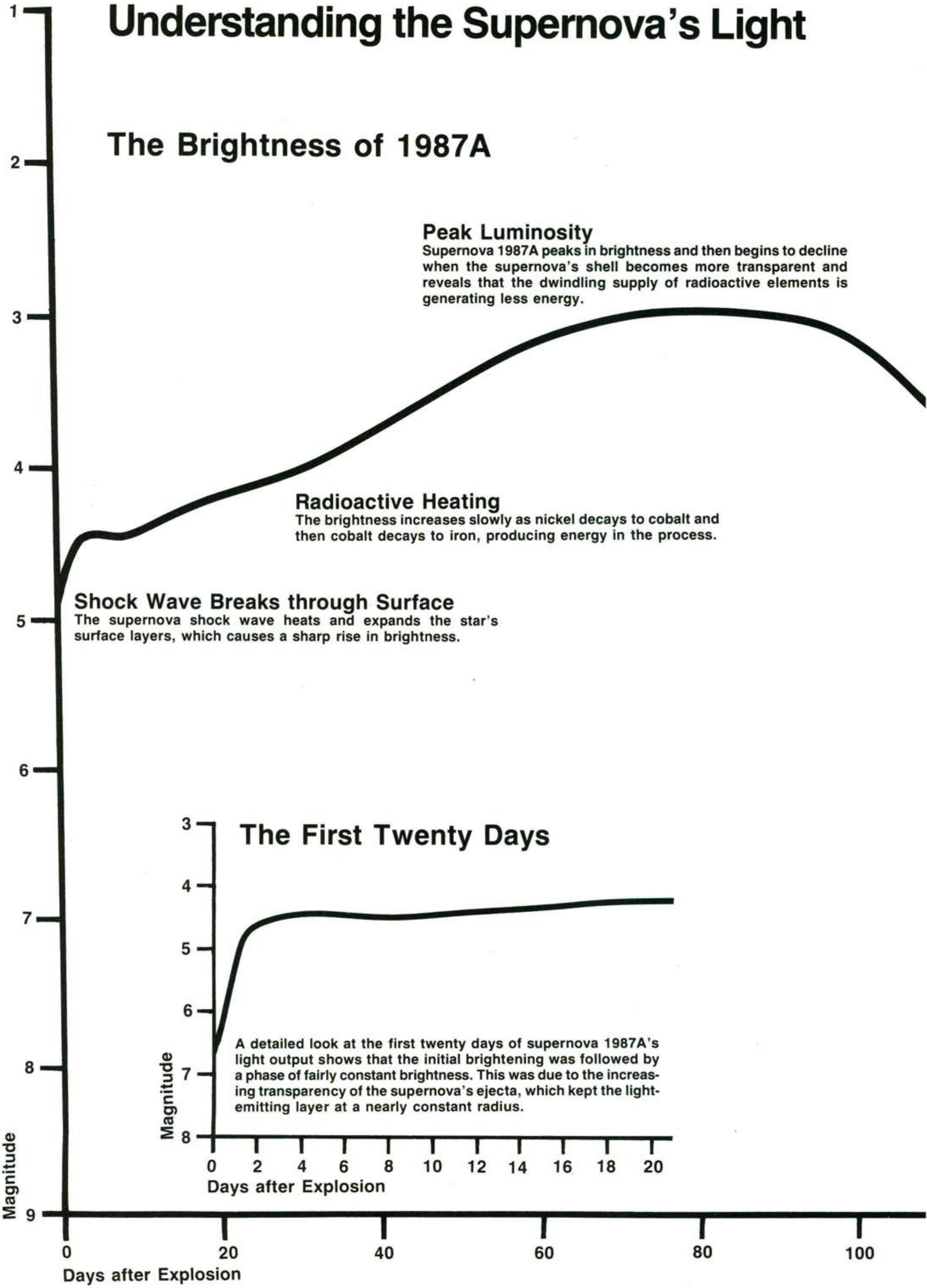
The temperature of the supernova and the average energy of the emitted neutrinos are derived from the energies of the positrons produced by the neutrino interactions and from the known characteristics of the neutrino detectors. The average energy of the observed neutrinos was in the range of 10 million to 15 million electron volts, which matched predictions for the electron antineutrinos. The derived temperature of the supernova was about 50 billion kelvins.

Astronomers used the neutrino observations to calculate the energy carried away from the supernova by all the electron antineutrinos. Because the electron antineutrinos represent about one sixth of the total neutrinos emitted by the supernova, astronomers next determined the total energy released by all neutrinos — 3 x $10^{53}$ ergs. This is roughly one thousand times the amount of energy that our Sun will produce in its entire 10-billion-year lifetime — or the amount of energy the Milky Way Galaxy emits in ten years — and the neutrino energy was released in a few seconds.

All of these numbers agree with the standard theoretical models astronomers have developed to explain supernovae. The neutrinos from 1987A escaped after the star collapsed, the emission lasted for several seconds, the neutrinos had the right average energy, and the temperature and total energy of the explosion were all close to expectations. For the first time astronomers got a close look at the physics of a collapsing star, and most of the theoretical predictions turned out to be remarkably accurate.

The neutrino results may also have important implications in particle physics. The detections offer a new way to determine the mass of the neutrino, the neutrino's lifetime, and other important properties of this fundamental particle.

# Understanding the Supernova's Light



## The Brightness of 1987A

**Peak Luminosity**
Supernova 1987A peaks in brightness and then begins to decline when the supernova's shell becomes more transparent and reveals that the dwindling supply of radioactive elements is generating less energy.

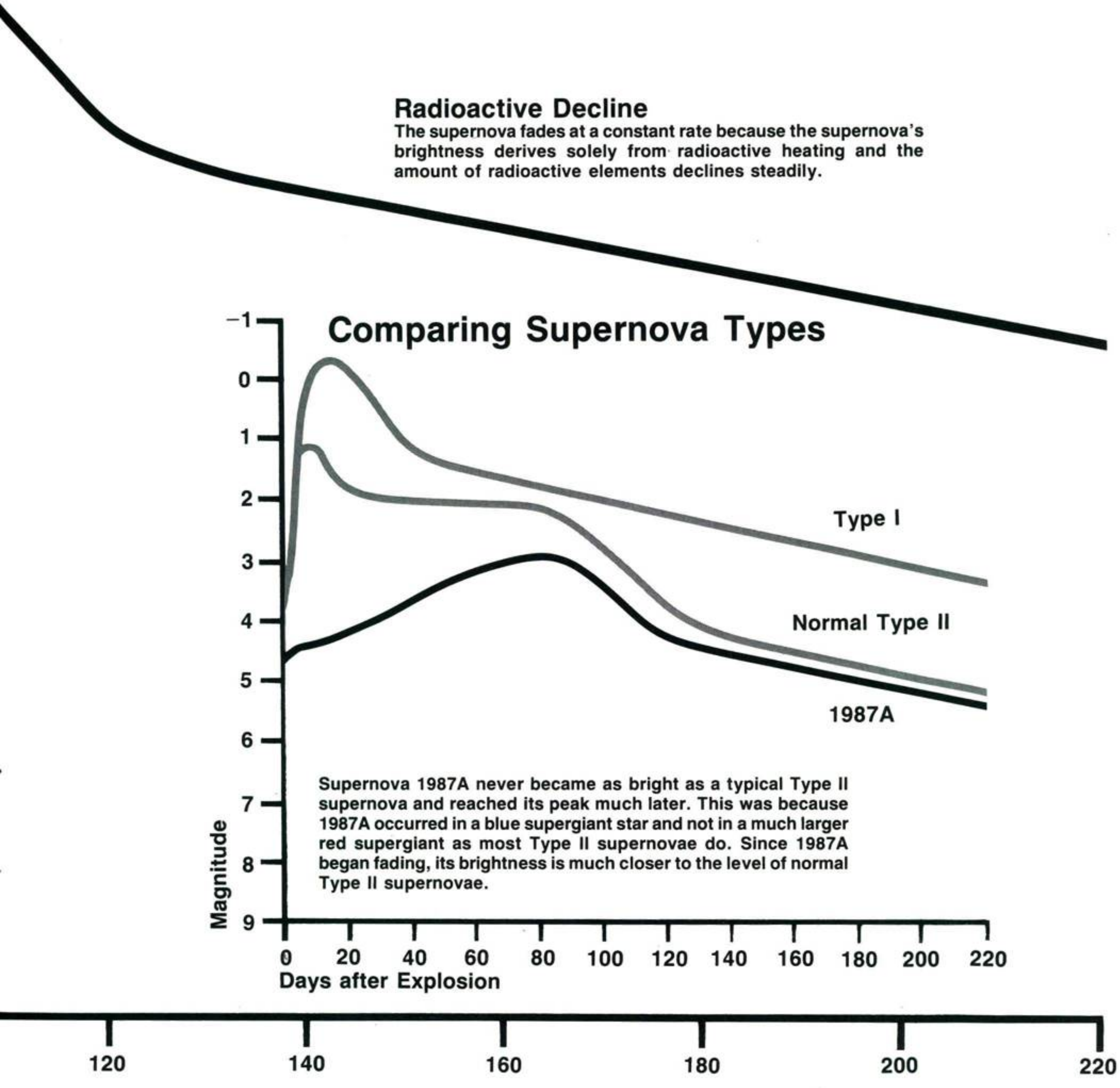
**Radioactive Heating**
The brightness increases slowly as nickel decays to cobalt and then cobalt decays to iron, producing energy in the process.

**Shock Wave Breaks through Surface**
The supernova shock wave heats and expands the star's surface layers, which causes a sharp rise in brightness.

### The First Twenty Days

A detailed look at the first twenty days of supernova 1987A's light output shows that the initial brightening was followed by a phase of fairly constant brightness. This was due to the increasing transparency of the supernova's ejecta, which kept the light-emitting layer at a nearly constant radius.

Magnitude
1
2
3
4
5
6
7
8
9
Days after Explosion
0
20
40
60
80
100
Magnitude
3
4
5
6
7
8
Days after Explosion
0
2
4
6
8
10
12
14
16
18
20



Visual magnitudes for supernova 1987A courtesy Mark Phillips, Cerro-Tololo Interamerican Observatory, and Michael Feast, South African Astronomical Observatory.

## Radioactive Decline

The supernova fades at a constant rate because the supernova's brightness derives solely from radioactive heating and the amount of radioactive elements declines steadily.

## Comparing Supernova Types

Supernova 1987A never became as bright as a typical Type II supernova and reached its peak much later. This was because 1987A occurred in a blue supergiant star and not in a much larger red supergiant as most Type II supernovae do. Since 1987A began fading, its brightness is much closer to the level of normal Type II supernovae.

Magnitude
-1
0
1
2
3
4
5
6
7
8
9
Type I
Normal Type II
1987A
0
20
40
60
80
100
120
140
160
180
200
220
Days after Explosion
120
140
160
180
200
220

The mass of the neutrino, in turn, could have a significant effect in astronomy. Whether the universe will continue to expand forever or one day reach a maximum size and then begin contracting depends on the amount of matter in the universe. Neutrinos are so numerous that even if each neutrino has just a small mass, the total mass of all neutrinos could be large enough to reverse the expansion of the universe.

Initial estimates of the neutrino mass from the supernova 1987A data show that the mass is too small to reverse universal expansion. The best current estimates place an upper limit on the neutrino's mass of about 16 electron volts, and an actual value much lower is certainly possible.

The neutrino detections from 1987A are highly significant and give astronomers the first direct confirmation of the theories about stellar collapse and subsequent supernovae. But the number of detected neutrinos is still quite small. Any statistical analysis of the nineteen recorded events runs into problems because of the small sample.

**The neutron star formed by the 1987A explosion probably will be visible one day as a pulsar.**

Not until a supernova explodes in our Galaxy will large numbers of neutrinos be recorded. Because the number of detected neutrinos falls with the square of the distance to the source, even a supernova in the Andromeda Galaxy is beyond detection. However, a supernova in our Galaxy would give a substantial signal. A supernova 5,000 parsecs from Earth — about halfway to the Milky Way's center — would yield perhaps one thousand neutrinos in each detector. A supernova only 500 parsecs away could give rise to as many as 100,000 neutrinos in each detector. When the next Milky Way supernova occurs — even if its visible light is hidden from us by dust — the neutrino signature from this supernova will be unmistakable and even more valuable than that from 1987A.

### Destroying the Star

As the shock wave moves out through the star, the core of the star remains behind. The collapse began when the core became larger than the Chandrasekhar limit, so the core cannot settle down to become a white dwarf. Instead the core becomes a neutron star. The collapse crushes the iron in the core to densities as great as or greater than an atomic nucleus, which, in effect, makes the core one giant nucleus. In the case of Sanduleak −69°202 this "nucleus" contains 1.4 solar masses of material.

In the same way that electrons become degenerate in a white dwarf, the neutrons become degenerate in a neutron star. The degenerate neutrons provide the pressure needed to keep the remnant from contracting any further. The neutron star formed by the 1987A explosion probably will be visible one day as a pulsar — a rapidly rotating neutron star with a large magnetic field that beams radiation in narrow pulses.

Along with everything else the neutrinos confirmed that a neutron star was born in the core of the supernova. Astronomers calculated the size of the remnant from the observed neutrino data and found that the neutron star was about 10 to 20 kilometers in diameter, which also agreed with theoretical predictions.

The neutrinos told astronomers a great deal about what happened at the heart of supernova 1987A, but they do not tell the fate of the shock wave. The shock wave forms in the interior of the iron core, some eight tenths of a solar mass out from the star's center. This means the shock wave must fight through the still-collapsing outer core before it can destroy the rest of the star. How this occurs is the major unsolved mystery of supernovae production.

If the core bounce is strong enough and the total size of the iron core is not too large, the shock wave should break through the outer core in ten thousandths to twenty thousandths of a second. If those conditions are not met, however, current supernova theory predicts the shock wave will stall. At this point the shock wave must be reenergized or the supernova will die, but there is no generally accepted mechanism to accomplish this.

The question of how the shock wave gets through the collapsing outer core is the most significant remaining problem in supernova physics. And unfortunately this is one question supernova 1987A has not helped to resolve. Neutrinos from the supernova can in principle shed light on this area, but the nineteen neutrinos detected from 1987A did not provide enough information to accurately model the entire explosion process.

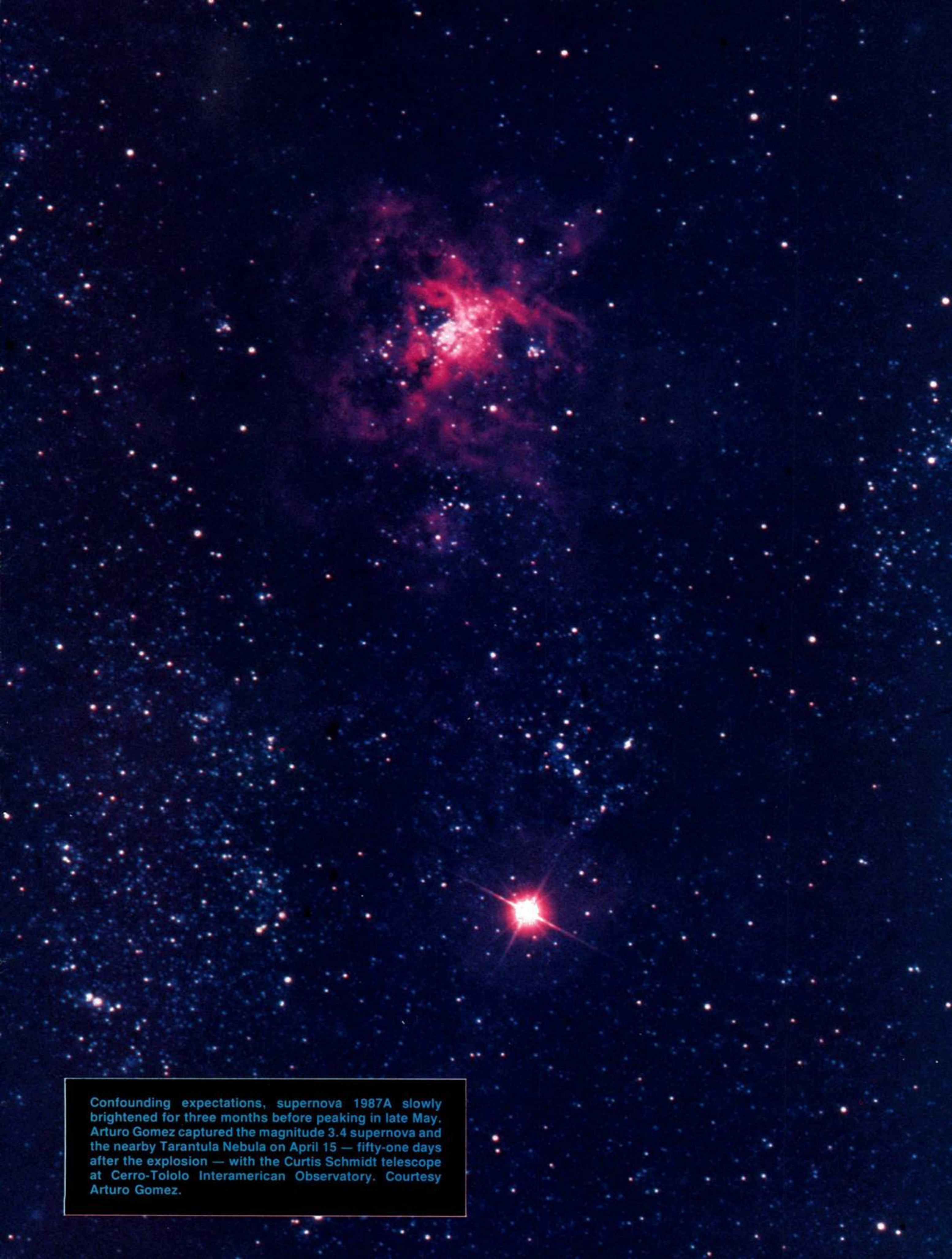
Conditions during the supernova explosion also create new elements from the ones previously made by nuclear fusion. The supernova produces an extraordinarily large number of free neutrons that can then be captured by the existing elements. In this way all the elements heavier than iron are formed rapidly inside supernovae. When the star explodes, these elements are strewn through space, along with the ones synthesized in nuclear reactions before the star died.

Once the shock wave breaks through the outer core, it rips through the rest of the star at a speed of some 30,000 kilometers per second. The shock violently heats the gases it passes through and causes further nuclear reactions in some of the gas.

Approximately one-and-a-half hours after the core of Sanduleak −69°202 collapsed, the shock wave reached the surface of the star. Until this time no electromagnetic radiation from the explosion had reached the outside world. The neutrinos offered the only evidence that the star had become a supernova, and neither of the neutrino detectors is monitored continuously.

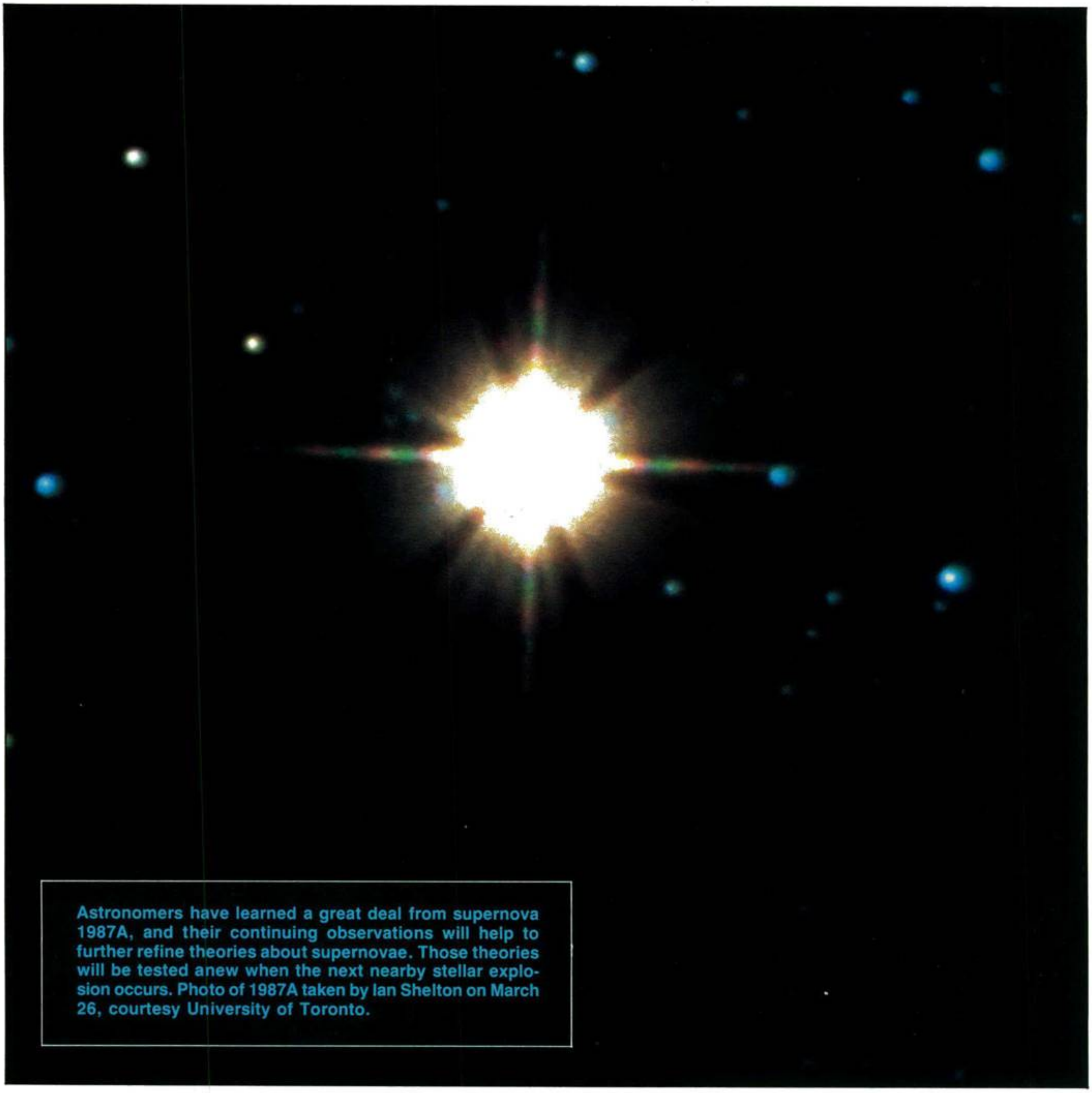
Instantly the shock heated the gases at the surface of the star to a temperature of 100,000 kelvins or higher. Gas at this temperature emits copious amounts of high-energy electromagnetic radiation, mostly ultraviolet and x-rays. This brief pulse of radiation went unobserved, however, because none of the satellites capable of observing at these wavelengths was pointed toward the Large Magellanic Cloud.

In fact, the supernova was not noticed until after the high-energy pulse began. Albert Jones, a New Zealand amateur astronomer, did not see the supernova when he observed the LMC at 9:22 UT on the night of February 23, when the high-energy radiation was already bathing Earth. The supernova was visually no brighter than magnitude 7.5 at the time.



Confounding expectations, supernova 1987A slowly brightened for three months before peaking in late May. Arturo Gomez captured the magnitude 3.4 supernova and the nearby Tarantula Nebula on April 15 — fifty-one days after the explosion — with the Curtis Schmidt telescope at Cerro-Tololo Interamerican Observatory. Courtesy Arturo Gomez.

The material that once composed Sanduleak −69°202 — rich in heavy elements like carbon and oxygen as well as hydrogen and helium — was ejected by the force of the supernova explosion. Years from now Earthbound observers will see this material as a supernova remnant. Photo of the Veil supernova remnant taken with the 48-inch Schmidt camera on Palomar Mountain, © 1959 by Palomar Observatory.



Astronomers have learned a great deal from supernova 1987A, and their continuing observations will help to further refine theories about supernovae. Those theories will be tested anew when the next nearby stellar explosion occurs. Photo of 1987A taken by Ian Shelton on March 26, courtesy University of Toronto.

A short time later Robert McNaught at Siding Spring Observatory in Australia first recorded the supernova explosion. He caught the image of the supernova on a photograph he took at 10:38 UT on February 23. McNaught failed to develop the plate that night, however, and the 6th-magnitude object on his film remained undiscovered until the following day.

Astronomers throughout the Southern Hemisphere turned telescopes to supernova 1987A as soon as they learned of the discovery. J. Menzies at the South African Astronomical Observatory took the first spectra of the supernova at 19:00 UT on February 24, and radio astronomers at Fleurs Observatory in Australia first detected radio waves from the supernova at 10:00 UT on the 25th.

The *International Ultraviolet Explorer (IUE)* satellite first made ultraviolet measurements of the supernova on the evening of February 24. Just one day after the first visual observation the initial burst of ultraviolet light was already fading rapidly. The temperature of the supernova gases had fallen from about 100,000 kelvins to 15,000 kelvins in that short period, and the cooler gas emitted less high-energy radiation. The ultraviolet brightness of 1987A continued to fall as the supernova cooled further.

## Observing the Explosion

Astronomers were primarily interested in observing the supernova's light. The light would tell them the exact position of the supernova, so they could learn which star had exploded. Spectra of the supernova would allow them to see the elements created in Sanduleak −69°202 and in the explosion and to follow the dynamics of the expanding supernova. And measuring the brightness of the supernova at as many wavelengths as possible would tell them the source of the supernova's energy. Information from each of these areas proved to be important for understanding the nature of 1987A and relating these findings to supernovae in general.

Once astronomers pinned down the position of supernova 1987A, they realized that at least part of their theory needed revision. The exact position corresponded to what used to be the star Sanduleak −69°202. Astronomers knew the main characteristics of that star from earlier observations. It was a blue supergiant star with a mass close to twenty solar masses and a visual magnitude of 12.36.

Theory predicted that Type II supernovae like 1987A should occur in the much larger red supergiant stars. In retrospect the problem was not as serious as many astronomers initially thought, because the differences concerned only the outer layers of the stars. Although most models of supernova explosions begin with a red supergiant star, slight alterations in the evolution of the star can cause the star to explode as a blue supergiant. And, most importantly, the physics of how the core collapses is the same regardless of whether the star was red or blue. The reason we have not seen other supernovae from blue supergiants is because these supernovae are rarer and they are not as bright. Thus, astronomers cannot see them from as large distances as they can see supernovae from red supergiants.

The question now is not whether a blue supergiant can explode, but whether Sanduleak −69°202 was once a red supergiant. One group of astronomers believes that some physical characteristic of the star precluded the star from becoming a red supergiant. The amount of elements heavier than helium could play a role. Heavy elements absorb radiation easier than hydrogen and helium, so a star containing a lot of heavy elements would tend to expand more when its core begins contracting than a star without a lot of heavy elements. The lower abundance of elements heavier than helium in the LMC compared to the abundance in the Milky Way could therefore be a major reason Sanduleak −69°202 was blue.

Another group of astronomers points out that there are lots of red supergiants in the LMC. These astronomers believe Sanduleak −69°202 was once a red supergiant that expelled some of its outer material in a "stellar wind." If this is true, the still expanding shock wave will eventually run into this material and cause it to glow. The *IUE* satellite has already detected radiation that could be from this material. Continuing observations should provide a more definitive answer.

### An Odd Light Curve

The light output of supernova 1987A was also unexpected. Most observed supernovae quickly reach a peak brightness and then slowly fade. Supernova 1987A, however, initially brightened to only a small percentage of the brightness of a typical supernova and then began to fade. Spectra revealed the supernova was also cooling at an unprecedented rate and that the outer layers of the supernova were becoming transparent abnormally fast.

Once astronomers learned Sanduleak −69°202 was a blue supergiant, however, the mystery vanished. Because a blue supergiant is smaller and more dense than a red supergiant, more of the energy released by the explosion is consumed in tearing the star apart. This explains both the low brightness and the unusual spectra of supernova 1987A.

The supernova started to brighten again after the first week, reaching a peak on May 20. The energy for this increase in luminosity came from the radioactive decay of nickel. About 0.07 solar mass of nickel formed in the star when the expanding shock wave violently heated the oxygen layer and caused nuclear reactions that create nickel. Nickel first decays to cobalt and then to iron, releasing heat in the process.

Stan Woosley of Lick Observatory predicted this scenario shortly after the supernova began to brighten. As the outer layers of the expanding supernova became more transparent, the layers heated by the radioactive decay became visible and the supernova brightened.

The first proof of this effect came about 130 days after the explosion. By then the supernova was already fading, but at this time the brightness began falling at the exponential rate predicted for the radioactive decay. Further proof should come from the Japanese *Ginga* satellite and the Russian Mir space station. Both are equipped to look for the gamma rays emitted when cobalt decays to iron.

**The question now is not whether Sanduleak −69°202 was a blue supergiant when it exploded, but whether it was once a red supergiant.**

### Future Observations

In fact, observations are continuing at all wavelengths. Theoretical astronomers are making predictions about how the supernova will behave in the next several years and beyond. How close their predictions are to the actual observations will be another important test of our supernova theories.

Much of the interest will be centered on the high-energy end of the electromagnetic spectrum. Ultraviolet emissions from the supernova, which dropped to very low levels shortly after the explosion, should increase into early 1988. Gamma rays from the radioactive decay of cobalt to iron should first be seen in late 1987 or early 1988, which would confirm once and for all that this is the major process currently energizing the supernova. X-rays created as the higher energy gamma rays make their way through the still opaque inner regions have recently been seen, another sign that the expanding shell is opening up.

The neutron star is still buried deep within the expanding debris of the supernova and probably won't be visible for a couple of years. One indirect piece of evidence that would indicate the neutron star's existence is the falling off of the supernova's luminosity at a different rate. Right now radioactive decay can completely explain the light curve, but a future deviation from the exponential decline would be strong evidence that a pulsar is also contributing to the supernova's brightness.

Supernova 1987A will remain an object of intense scrutiny for a long time. As the shell of material expands, it becomes more transparent, opening up like a flower to reveal previously hidden details to Earthbound astronomers.

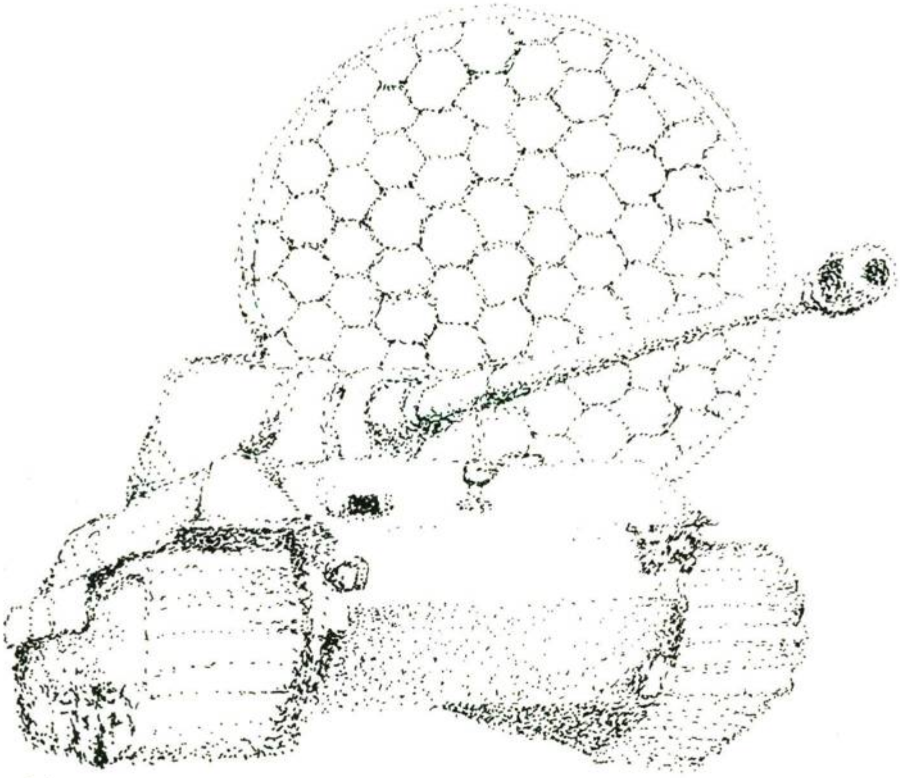
Long after the supernova fades from our view, 1987A's shock wave may encounter an interstellar cloud. Perhaps a small condensation will form in that cloud and eventually grow to starhood. If that star is large enough, it may also explode. Several million years from now our distant ancestors may get another spectacular view, as a supernova born from the debris of 1987A lights up the Earth's southern sky.

## A Tall Tale of Telescope Making

Even though the Germans had lost World War II, the nomads of the Sahara were still determined to destroy anything that looked German in the 1950s. I know. Those crazed nomads bombed my homemade, German tank-mounted, 36-inch telescope — a marvel of technology I had cooked up in a little shed out in the backyard when I was only thirteen years old.

My dad worked for the State Department as a construction engineer in Africa, and we were stationed near the Sahara. I was surrounded by all the sand I would need to make my own glass. During the summer Dad took me with him on his many field trips, and I always took a sack with me and filled it with the purest sand I could find. When we got home, I would screen, wash, and lay the sand out in an enclosed place to dry and then bag it again. It wasn't long before I had several hundred pounds of sand stored in the shed Dad said could be my workshop.

I'd also sneak out at night and scrape all the rust off the link fence around the machine shop. (Dad couldn't figure out how the fence stayed so brightly polished.) I stored the rust in Mom's big aluminum pressure cooker, which I had already appropriated for the purpose. Several pounds of Mom's garden lime turned up in my shed too.



Though I perfected the genteel art of careful acquisition to obtain most of the materials for my telescope, I actually purchased chemicals from the local chemist with my own allowance. In Africa prescriptions were unheard of. If you needed a shot, you asked the chemist. So I bought two bags of boric oxide, a bag of soda and alumina, and some small bottles of potassium oxide and arsenic oxide. The good old *Encyclopedia Britannica* had given me the correct formula for gunpowder, so I had no reason to doubt the encyclopedia's formula and composition for Pyrex brand glass.

I constructed a rotating mold from bits and pieces of hardware I found around the house. Dad was supervising the construction of a refinery, and some of the leftover firebrick found its way to my shed. I had also acquired a truck axle, some steel plate, and the shop's acetylene welding outfit. With these I fabricated a vertical standing "lazy Susan" and lined the 36-inch table with the firebrick and refractory cement. Then I laid out a honeycomb-like mold with bits of firebrick, allowing a 3-inch hole in the center of the casting.

I had also found a couple of industrial fans: one worked and the other didn't. So I welded the one set of blades onto the drive shaft stub, positioned the working fan close to it, and turned it on. Gradually the fan picked up speed, its wind spinning the other fan. And the whole assembly started to rotate! I timed the table's top spin at a constant eighteen revolutions per minute but fine-tuned it with a rheostat on the fan; I wanted to make an f/5 mirror, and, if I remembered correctly, a spin of eleven revolutions per minute was perfect.

My only problem now was getting enough heat. As I was mixing my concoction, I noticed how the sunlight glinted off the sand and — Eureka! —

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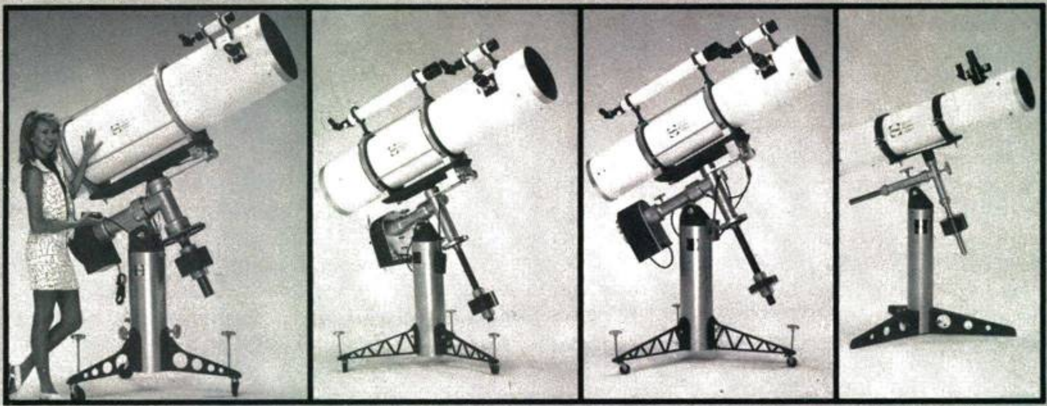

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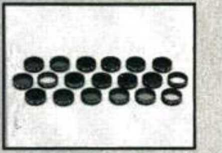

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| 15mm | 1¼″ | 52° | Yes | 130.00 | 69.00 |
| 20mm | 1¼″ | 52° | Yes | 140.00 | 79.00 |
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I decided I'd build some mirrors and melt the mix in the spinning mold itself.

Nothing could deter me. Back in the 1950s it was chic to shave with a Blue Blade and a magnifying mirror. These neat little mirrors had a focal point about eight feet away. One day Dad lost his shaving mirror. All the men in camp lost theirs too. I mounted all of them on a frame I could turn to follow the Sun. But still there was not enough heat. So flat mirrors began to disappear. The local newspapers reported a rash of mysterious mirror nabbings.

But it was enough. Early one summer morning I turned on my fan. It spun the lazy Susan, and the mirrors turned the mold area into a pool of blue-white fire. With a long dipper I began ladling my sand mix into the rotating mold. Almost as soon as it fell, it melted. It wasn't long before the mold was brimming with molten glass. And, of course, that glass was shaped into a concave shape by the spinning of the mold.

As the Sun went down, the mix began to solidify. I dismantled the mirrors and went to bed, leaving the whole shebang turning through the night. I kept that sucker spinning for the rest of the week as it cooled.

Meanwhile I welded a dome that just fit over the mold. When the glass was cool enough, I welded the dome to the mold base, pulled a vacuum with a pump, and mirrored the surface. I couldn't care less about perfection; if that baby could reflect light, it would make me a telescope! The next day I released the vacuum and cut the dome off. The mirror looked perfect, and the old razor blade test put it at near perfection.

I had a problem though, or so I thought. I'd built my mirror, but how would I use it? That baby was big. I'd need a gun mount to turn it. Gun mount! By golly, I had it! When the war ended, a bunch of small, German mobile guns had been left in the desert for scrap. I would use them to make a genuine German mount for my telescope. And it would be mobile, to boot! I ventured into the desert many times over the next few weeks and located different pieces of abandoned hardware. I won't tell you how difficult making the mount was. But by that fall I had one of those minitanks ready to gas up. One night I borrowed dad's jeep, took some fuel and batteries to my prize, and finished building the mount just before dawn.

I slept all day and Mom thought I was sick. But that night I crept out again and reached my German telescope two hours later — it's tough walking through sand.

It took only about twenty minutes to move my German Equatorial (an appropriate name because she was both German and found near the equator) to my shed. That night I could hardly sleep. I was dreaming of how I would mount my mirror and take my first look at the Lagoon Nebula.

The next day I welded a 36-inch-diameter, 8-foot-long piece of refinery pipe to the cannon. The barrel of the cannon provided all the stiffening I'd need and would make a great sighting scope. I hoisted the mirror up to the back of my scope and welded its mounts in place.

I'd precalculated positions before welding, and the focal point of the image would be located just inside the cabin. I welded a homemade focuser assembly in the cabin; a secondary reflecting mirror spider was bolted to the scope's objective end. My German Equatorial wasn't a thing of beauty, but she was a work of love. I painted, polished, and scrubbed her until she shone. And then she was done. Only the sighting trials needed to be completed.

On October 4, 1953, I first took her into the desert. I'd already located a high ridge my telescope could reach. That night we clanked to the site. I tried to rock her a bit, but only an earthquake could shake my massive German Equatorial. I shut the diesel down and used the electric motors to slew the scope into position. I got her aimed at the Moon, using the spotting cannon, and then moved my head to the objective I'd made from some Zeiss camera lenses I'd found.

Oh, the glory I experienced on that crystal clear night. They say you never forget your first look at the stars. I know I will never forget mine! The mountains on the Moon were so clear you could count pebbles. I skewed the scope toward Saturn, then Jupiter. The heavens were ablaze with glory! The dust paths of the Orion Nebula were the blackest black, the colors vivid! I must have looked at a thousand wondrous things that first night of my life!

But, alas, it was not to last. My regular comings and goings aroused the curiosity of the desert nomads. They had fought against the Germans in World War II, and here I was, driving a German tank back and forth across the desert twice every night for a month. They must have thought that 36-inch-diameter tube was the barrel of the biggest gun they'd ever seen.

At around 4 a.m. on November 1, it happened. As I was heading back I noticed several flashing lights moving across the sky. Were they meteors? No, were they . . . *KerWHAM!* My head rang like a bell! My German Equatorial had been hit by mortar fire. As I dove to the ground I could see hundreds of nomads.

I don't have to tell you I ran. I ran so fast my shirt tails didn't slap my fanny. *KerWHAM! KerWHAM!* They kept hitting my poor telescope till they blew her sky high. The newspapers reported that some hidden World War II munitions dump had blown up, lighting the sky for hundreds of miles around.

The next morning I rushed out to look for salvageable remains. There was none. Just one heck of a big crater, slowly being filled by wind-blown sand.

Well, that was the end of my first telescope. But I've got at least one consoling thought. They blew her so high she reached space before I did. Years later when I found that eight-foot tube welded to a twisted tank cannon orbiting 832 miles up. . . but that's another story.

*Henry C. Gernhardt, Jr.*
Huntington, West Virginia

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## An Eclipse through the Eyes of a Child

The penumbral eclipse of April 13, 1987, wasn't supposed to be spectacular, but then that depends on how you observed it. I watched with my three-year-old daughter, who gave me new insights into the night sky.

By the time the Moon had risen in Arizona, the eclipse was half over. I settled into a lawn chair with my daughter in my lap. From our backyard we had a beautiful view of the Moon, and the night was clear and cloudless. The dimming of the Moon was supposed to be modest and possibly imperceptible, so I thought I would take advantage of the keener eyesight of youth.

"Elizabeth, does the top part of the Moon look darker than the rest?"

"Nope." Was that the response of an untrained or an unbiased eye? But Elizabeth continued, "It's a Full Moon, isn't it, Daddy?"

"It's almost full."

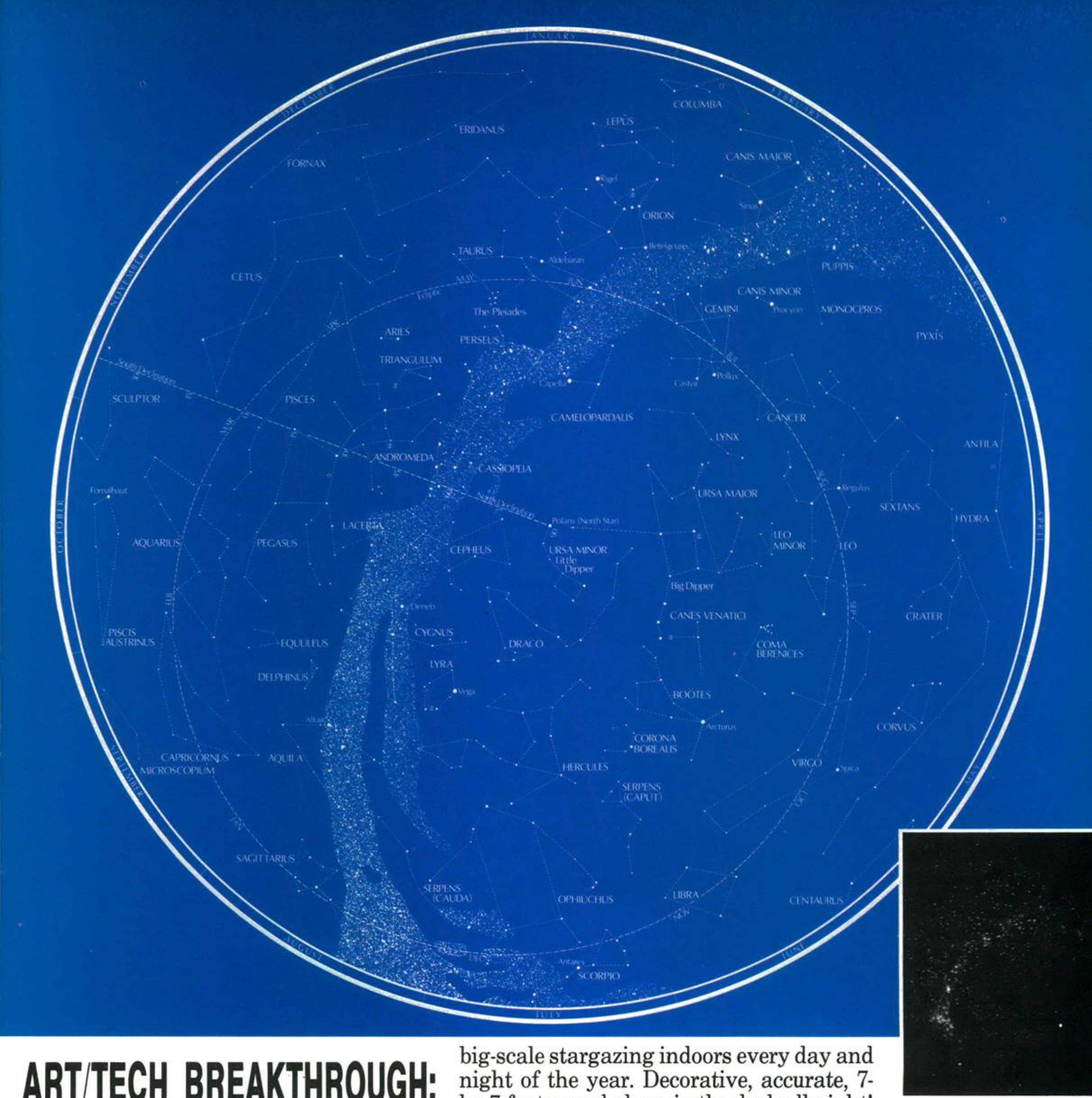
"It's full, but it didn't eat, did it?"

"No, the Moon doesn't eat."

"After it's full, it gets little again, huh, Daddy?"

"That's right, Elizabeth."

"And then it gets big again, and then small again, and then big again." Elizabeth is bright for her age, but she knew a lot more about the Moon than I thought she did. "Daddy, I see the Bunny-in-the-Moon." I've always thought it was easier to see the shape of a rabbit in the Moon than a man in the Moon.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NOVEMBER
DECEMBER
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SCULPTOR
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"It's not the real bunny though, is it? It's not the bunny that comes on Easter."

"No Elizabeth, it's not a bunny at all — it just *looks* like a bunny."

As the eclipse started to wane, so did Elizabeth's interest in the Moon. "The stars don't move," she said.

"That's right, Elizabeth." I then tried to get her thinking about the Moon's apparent motion from east to west and its actual movement from west to east. That didn't go over too well; Elizabeth was intent on the stars now. "Which star is mine?"

I've told her that "her star" is bright Aldebaran in Taurus because Elizabeth is a Taurus. Normally the eye-of-the-Bull is easy to find because Taurus is charging the conspicuous giant Orion. Not so on this eclipse night. One of the wandering stars, Mars, was in the same general vicinity as Aldebaran. I pointed out the two reddish "stars" to Elizabeth and told her one of them was her star, Aldebaran, and the other was the planet Mars. She was content with that explanation.

She wasn't content when I told her the eclipse was over and it was time for her to go to bed. I don't think she realized she had seen an eclipse — as predicted, the eclipse was undramatic — but viewing the heavens through the eyes of a three year old can make even a penumbral eclipse worthwhile.

*Joseph T. Hepworth*
Tempe, Arizona

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## Thinking Galaxies in 1755

Does the name Immanuel Kant mean anything to you? If you've read about eighteenth-century philosophy and astronomy, you may have come across the German thinker Immanuel Kant throughout the literature on both subjects. In the eighteenth century Kant proposed that certain fuzzy patches of light in the sky were vast collections of stars far beyond the Milky Way. Without sophisticated telescopes or twentieth-century information Kant believed galaxies existed outside the Milky Way. How could he have known?

Kant thought through the logic of his argument and wrote about his ideas elegantly while making a bid for academic fame in the Imperial Germany of Frederick the Great. In 1755 Kant celebrated his thirtieth birthday and gained a doctoral degree and a professorship in his home town of Konigsberg. In the same year he published the *General Natural History and Theory of the Heavens*, a brilliant astronomical essay.

The strong belief Kant held in Newtonian views — that everything in the universe operated by principles of force — is reflected in the book's subtitle, "An Essay on the Constitution and Mechanical Origin of the Whole Universe Treated According to Newton's Own Principles." Kant believed the universe was constructed so that a parallel order existed in each part of the cosmos. Following these lines in the book he proposed "A Systematic Constitution of the Universe."

Kant began by discussing how planets revolve about the Sun more or less in the same plane, just as the particles in Saturn's rings revolve in a common plane. Using this idea as a basis for the observed Milky Way, Kant believed stars must revolve about a common center like the planets. "It is astonishing that the observers of the heavens have not long since been moved by the character of this perceptibly distinctive zone in the heavens, to deduce from its special determinations regarding the positions and distribution of the fixed stars," wrote Kant.

Kant believed the appearance of the Milky Way across the sky should suggest a form that observers could deduce. He chided astronomers for their lack of attention to the Milky Way's appearance, which is so "perceptibly different from the indefiniteness of chance, that attentive astronomers ought to have been thereby led, as a matter of course, to seek carefully for the explanation of such a phenomenon." Kant decided to investigate what astronomers had previously ignored.

Just as the planets move around the Sun, so must the Sun move, he reasoned, and the Sun's motion must be affected by the attraction of other stars, according to Newtonian principles. Thus Kant envisioned the Milky Way as a vast collection of stars rotating roughly in the same plane around a common center.

But that was just the beginning. Kant's bold imagination took a breathtaking leap in the next part of his work. "I come now to that part of my theory which gives it its greatest charm, by the sublime idea which it presents of the plan of the creation. If a system of fixed stars which are related in their positions to a common plane, as we have delineated the Milky Way to be, be so far removed from us that the individual stars of which it consists are no longer sensibly distinguishable even by the telescope; if such a world of fixed stars is beheld at such an immense distance from the eye of the spectator situated outside of it, then this world will appear as a small patch whose figure will be circular if its plane is presented directly, and elliptical if it is seen from the side or obliquely."

Anyone who has ever looked at a galaxy through a modern telescope knows that Kant's description matches the telescopic view of face-on and edge-on galaxies. These fuzzy patches in the sky, usually oval in appearance, constitute a large portion of what were known in Kant's time as "nebulous stars." Observers of his day noticed that irregular patches like Orion's M42 were quite different from the more regular patches that would prove to be galaxies. Quoting a French astronomer, Kant described these objects as "small luminous patches, only a little more brilliant than the dark background of the heavens. They present the figure of ellipses more or less open; and their light is much feebler than that of any other object we can perceive in the heavens."

Kant was confident writing: "If conjectures, with which analogy and observation perfectly agree in supporting each other, have the same value as formal proofs, then the certainty of these systems [galaxies] must be regarded as established." Astonishingly, despite the radical ideas he advanced, no one knows whether or not Kant ever looked through a telescope.

Kant was without doubt one of the pre-eminent thinkers the world has known, making incredible mental leaps in scientific understanding. In a real sense he was the first human being to propose that both the Milky Way and M31 are galaxies.

But Kant didn't stop with this. Like modern day cosmologists, Kant saw two aspects of the possibility of "the decay of nature," or entropy. He believed either galaxies will move away from each other until they have "exhausted all motion" or that the force of gravity will draw all matter back together so a new fire will be ignited, "dispersing and scattering these elements again in this way with a power of expansion proportional to the heat [involved]." He seemed to favor the latter as the fate of the universe.

To those in the twentieth century, Kant's youthful writing may seem like some kind of prestidigitation. It isn't, of course. What comes through is the forceful thinking of a great mind. "All that is finite," he ended, "whatever has a beginning and an origin, has the mark of its limited nature in itself; it must perish and have an end. In the same way whole worlds and systems quit the stage of the universe, after they have played out their parts." Few, however, played as perceptive a role as Kant did.

*John Mood*
San Diego, California

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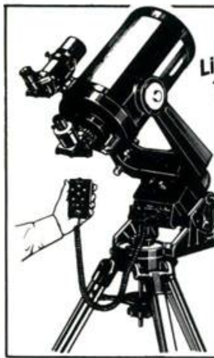

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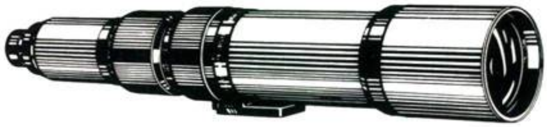

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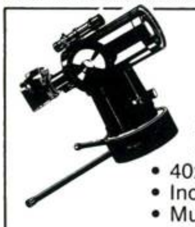

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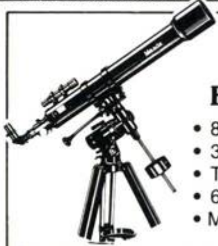

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**— Astronomy (11/87)**

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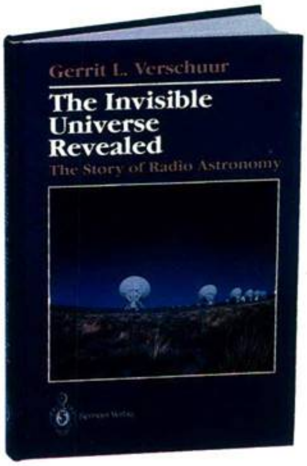

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**— Nature (4/87)**

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**— New Scientist (4/87)**

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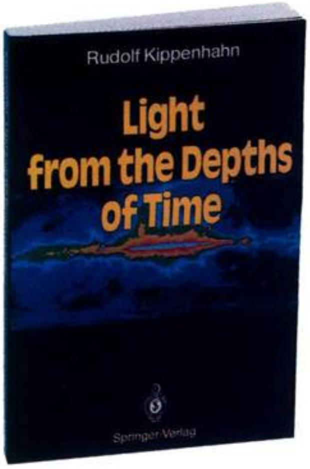

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# ASTRONOMY
# In Focus

## Is the CAT Leading Us Astray?

Dear Sir / I enjoyed David J. Eicher's article on computer aid for telescopes, "The ATI 'CAT': The Wave of the Future" (Equipment Atlas, December 1987). The article is well written, objective, and has excellent graphics. But as for the ATI CAT and similar products we now see on the market, I welcome them about as much as Izaak Walton would welcome fishing in a bass tournament or John Muir would welcome riding an all-terrain vehicle across the mountains.

The night sky still belongs to the curious observer who has a small scope, charts, books, and a lot of personal motivation. The danger is that newcomers to the hobby will think they need these devices to do anything meaningful, when in fact these devices will insulate the beginner from real progress.

"See one hundred galaxies per hour!" says one ad. That is thirty-six seconds to peruse the tenuous wonders of M33, not counting moving and focusing time. Humbug! That observer would do better to spend his money on a set of professional slides and stay inside where it is nice and warm. (Two thousand dollars buys a nice projector and a lot of slides and popcorn.)

Let us heed Mr. Eicher's advice given in *Deep Sky* magazine, Fall 1987: "Finding galaxies and nebulae in your telescope does not constitute deep-sky observing. Seeing's what it's all about. I mean *seeing*, critically examining faint objects with a sharp, patient eye . . . ."

George E. Allen
Omaha, Nebraska

## Dew Cap Suggestions

Sir / Harry Hammond's article "Build a Heated Dew Cap for Less than $10" (Equipment Atlas, November 1987) warmed the hearts of many who are plagued by dewing. However, I want to clear up a minor point because the article leaves the reader with the impression that each of the seven 2-ohm resistors must be rated at 10.3 watts.

While the entire circuit consumes 10.3 watts, each resistor consumes one seventh that amount, or about 1.47 watts. Resistors are rated not only in ohms but in the amount of watts they are designed to withstand. In this case use seven 2-ohm, 2-watt wire-wound resistors. If you choose to use thirty 0.47-ohm resistors, each resistor consumes 1/30th of the total consumption, or about 0.34 watts. In that case you can use 1/2-watt resistors, but specify wire-wound rather than the more common carbon resistors.

For those of you who have 120 volts available at your viewing site, the same equation shows that we can use seven 200-ohm resistors to get the same 10.3-watt total power consumption. These resistors would also be wire-wound, each rated at 2 watts or more. With the higher voltage it is more important, for safety reasons, to solder your leads and make sure everything is properly insulated.

Thomas Larsen
Van Nuys, California

Sir / "Build a Heated Dew Cap for Less than $10" by Harry Hammond doesn't emphasize that a reader attempting to build this dew cap could end up with a unit that doesn't work or that degrades optical performance or, worse, starts a fire and destroys the reader's instrument. Here is a technical explanation of why these situations could occur.

Mr. Hammond suggests putting a fuse in the wires that go to the heater, but he gives the value of the fuse as 15 amps, which is too high by an order of a magnitude. Because $P = IE$, then the current is $I = P/E$, or 10.2 watts/12 volts, or 850 milliamps. The fuse value should thus be in the neighborhood of 1.5 amps to protect the circuit. The value given may well have been a typo, but combined with the following problem, the results can be disastrous.

The author mentions power resistors several times, but he doesn't define the words. Resistors can be bought in power dissipation ratings from 1/8 watt to several hundred watts, and those with ratings of 1 watt or higher fall into the general classification of power resistors. The published circuit uses a series circuit, so each resistor must be able to dissipate $(0.85)^2$ x 2, or 1.45 watts (because $P = I^2R$). If you use a 1-watt "power" resistor, you will build a circuit that could generate enough heat to set fire to the paper dew cap.

The article suggests the alternative of using thirty 0.47-ohm resistors in a series. Those resistors would have to dissipate only 0.34 watts apiece ($0.85^2$ x 0.47 ohms), so half-watt resistors would provide enough dissipation.

In general, for a series circuit (1) find the total resistance by multiplying the number of resistors by the value of one resistor (if resistors are equal), (2) find the current by dividing applied voltage by total resistance ($I = E/R$), and (3) power dissipation for each resistor equals resistance multiplied by the total current ($P = IE$).

The skin temperature of the resistors is important. Ten watts dissipated by a 100-watt resistor will not appreciably raise the resistor's surface temperature, while the same 10 watts dissipated by a 10-watt resistor will make the surface hot to the touch. If the resistors are running at or near their value, the resulting "hot spots" will cause rising columns of heated air to form inside the dew cap, causing instantaneous bad seeing. Conversely, if the resistors are running too cool, the air temperature will not be raised enough to warm the glass above the dew point. The author doesn't explain this point, so you need to experiment before the project can be completed.

Kirk H. Taylor
Sunnyvale, California

*— Readers should clearly exercise care in building a heated dew cap. Use a large number of resistors and rate them conservatively. For safety reasons, we do not recommend 120-volt power for any dew cap circuit.*

Sir / Your article on dew caps was excellent ("Build a Heated Dew Cap for Less than $10" by Harry Hammond). Another method to try is using a Baskin and Robbins ice cream tub to build a superb dew cap for a C8 or equivalent telescope.

Knock out the bottom of the tub. Then paint the dew cap flat black on the inside, spray it silver on the outside, and cut out a hole for the counterweights. I laid some nichrome wire on the inside of the dew cap with tape, epoxied the wire in, and epoxied the inside of the tube to make it stiff. I then put black paint over that.

The nichrome wire pokes through two holes and is attached to the battery with alligator clips and suitable leads. The resulting "Baskin and Robbins Electrically Heated Dew Cap" works 100 percent of the time and costs almost nothing. It's also lightweight and tough.

Alan Macfarlane
Seattle, Washington

## Advice for the Beginning Telescope Maker

Sir / For years I have put off buying a telescope because the cost is so high. But, after watching the new PBS program, *The Ring of Truth*, I am considering building a telescope.

Please tell me how a first-time telescope maker gets started.

James Markby
Glen Ellyn, IL

*— We suggest that you read* Build Your Own Telescope *by Richard Berry or consider subscribing to* Telescope Making, *which is published by the same company that publishes ASTRONOMY.*

## Easy Way to Find True North

Sir / You can avoid the time-consuming measurements of finding true north and positioning the gnomon of your sundial exactly at the angle of your latitude as explained in "Watching Earth Move with the Shadow Clock" by Bruce McClure (Equipment Atlas, August 1987). The key is using a hollow tube for the gnomon. At night you can use the tube as a finder scope for Polaris by sighting the star through a hole at the center of the tube's base.

Note, though, that the tube must be about 5mm in diameter to help you locate Polaris.

Isaac Glaubman
Petah-Tikva, Israel

## Calculating Limiting Magnitude

Sir / I've had difficulty understanding the formula for determining limiting magnitude given in "Essentials of Telescope Performance," a sidebar to "Do Your Homework before You Buy" by Bill Volkart (October 1987). Could you explain how this is calculated for an aperture in millimeters?

Tom Quinn
Elk Grove, Illinois

*— The text is confusing because the formula gives the light-gathering power but not the limiting magnitude. Use this formula to determine limiting magnitude: LimMag = 6 + 2.5 log(LGP), where LPG stands for light-gathering power. For example, a 60mm refractor has a light gathering power of 100.*

*Working from the formula,*

$$\begin{aligned} \textit{limiting magnitude} &= 6 + 2.5 \log(100) \\ &= 6 + 2.5 \times 2 \\ &= 6 + 5 \\ &= 1 \end{aligned}$$

*These formulae assume the pupil of the eye is 6mm in diameter and the limiting magnitude of the naked eye is 6th magnitude.*

## Oops!

The map "Vesta's Path through the Beehive" on page 116 of the December 1987 issue was incorrectly labeled. Vesta's December 1 position should be at the lower left (instead of at the upper right) and the January 10 position should be at the upper right (instead of the lower left).

The biographical paragraph at the conclusion of "How Do Spiral Galaxies Spiral?" by Neil Comins and Laurence Marschall (December 1987) should have stated that Comins is an associate professor of physics at the University of Maine and that Marschall is a professor of physics at Gettysburg College.

### Behind the Scenes

## Theory, Observation, and Fun

A year ago this month an astronomical event startled the world: a faint star in the Large Magellanic Cloud blew itself to pieces. This month ASTRONOMY's Rich Talcott explores how supernovae occur — and why after millions of years of gradual evolution the core of a star self-destructs in a few thousandths of a second.

Rich has been following supernova 1987A since it blew up last year. He attended the fourth George Mason Fall Workshop in Astrophysics on the supernova last fall, where a hundred supernova scientists met to discuss what they'd learned from this distant cataclysm.

"What was most interesting," said Rich when he came back to our offices after the meeting, "is the interplay between theorists and observationalists. The theorists were really honing in on the physics."

"The observers were excited about all the new stuff they have seen. Everyone I talked to is looking forward to following the supernova as it continues to change."

Ah, to be an astronomer in such times! What a thrill to be living when understanding the very nature of the universe seems within our grasp. But amateur astronomy is equally rich in its pleasures. Although the hobby of astronomy deals less with physics than modern professional astronomy does, the universe remains open to us all.

Jupiter, for example, was a pleasure to watch last summer and fall. If you observed the giant planet regularly with a telescope, you surely saw the eruptive features in the North Equatorial Belt.

Or consider that unexpected observing treat, Comet Bradfield. I enjoyed following this modest little comet along its track more than I enjoyed Comet Halley the year before. And from our reader mail it's clear that many of you enjoyed Comet Bradfield too.

Because you were sending so many letters describing what you've observed, we created a new section of the magazine: Reader Reports, which begins on page 34. This section is open to all observers. We'd like to hear from you.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

Reader Reports

# Comet Bradfield Dazzles Backyard Observers

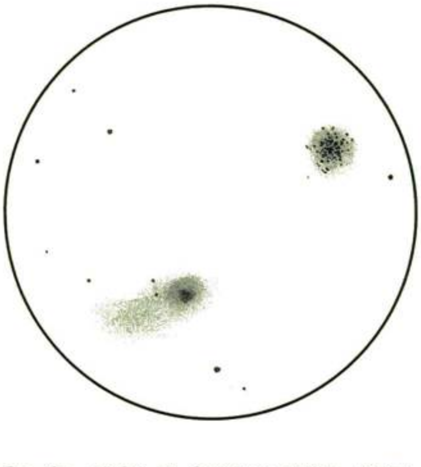
*Reader Reports is a new ASTRONOMY department that will cover sky events and reader projects in future issues. The department will appear periodically and feature written descriptions, photographs, and sketches of comets, asteroids, planetary phenomena, eclipses, occultations, novae, supernovae, and other newsworthy events. The editors of ASTRONOMY look forward to receiving your observations of the sky for possible inclusion in Reader Reports.*

**Comet Bradfield 1987s.** On August 11, 1987, Australian amateur astronomer William A. Bradfield discovered his thirteenth comet and became the first person to find that many comets in the twentieth century. A 10th-magnitude object at discovery, Comet Bradfield quickly brightened as it moved toward perihelion at 6h UT on November 7. By that date Bradfield had brightened to naked-eye visibility and had grown a 3°-long tail. Observers around the world spotted the comet in Ophiuchus, low in the evening sky over the southwestern horizon.

Bob Keller of the Warren Astronomical Society in Detroit first observed Bradfield on September 14, when it was a "hazy patch not more than 15° above the horizon." Yet he saw the comet develop a fan-shaped tail by September 25, and continue brightening until it was visible in 7x50 binoculars on October 13. At a star party held by Keller and other Warren members on Lake St. Clair, dozens of people viewed Comet Bradfield through an 8-inch telescope, the first time many of them had seen a comet.

Bradfield was an impressive sight by early October. During the first week of the month observers estimated its magnitude at around 7. On October 9, David Hanon of Ringgold, Georgia, first looked for the comet with 10x80 binoculars and the finder chart in the November 1987 ASTRONOMY. "I found the comet easily and estimated the tail at about 1° in length as viewed with my binoculars," said Hanon.

Howard Brewington of Newberry, South Carolina, photographed Comet Bradfield almost every clear night between September 23 and November 1. On the first night the comet was "low in the sky, only about 15° up, so I had to race against Earth's rotation." By October 13, after the Moon had moved out of the way and the comet became well placed for photography, Brewington photographed Bradfield again.



**On the night of October 22/23, 1987, Comet Bradfield passed 30′ southeast of the globular cluster M10 in Ophiuchus. John Stewart sketched the pair with a 13.1-inch f/4.5 Dobsonian at 58x at about 7:45 p.m. EDT. North is up and east to the left.**

"On my negatives the comet showed a dust tail almost 3/4° long and the hint of an ion tail," wrote Brewington. "After making an exposure, I checked the comet with 10x70 binoculars and it looked like a cotton ball. Visually it had no tail and not much concentration of light toward the center."

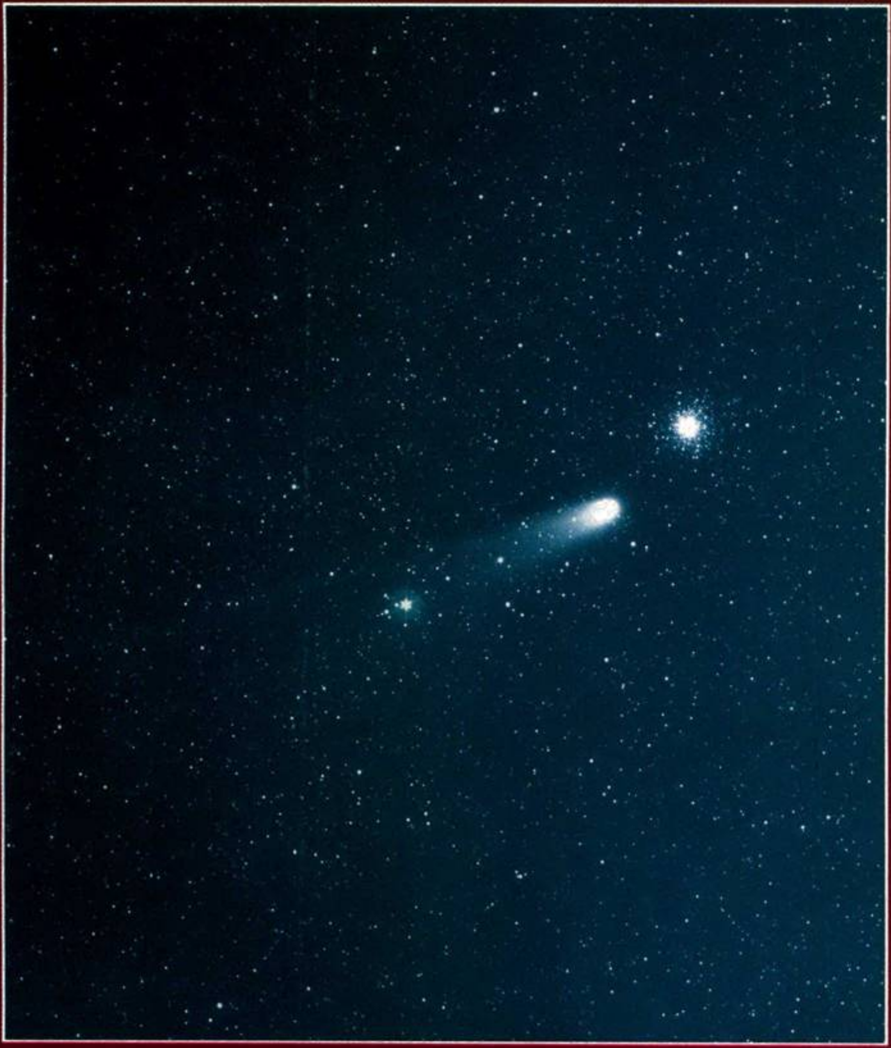
On October 22, Comet Bradfield passed within 30′ of the bright globular star cluster M10. On this night thousands of backyard astronomers observed the 6th-magnitude comet hanging just southeast of the distant cluster. Brewington recorded in his notebook that the comet seemed distinctly brighter than the cluster and that 10x70 binoculars revealed a 1/2°- to 3/4°-long dust tail. John J. Stewart of Manheim, Pennsylvania, sketched the pair of dissimilar objects with a 13.1-inch Dobsonian telescope. Stewart recorded in his notes that "the separation is about 30′. While I was observing this pair, a satellite passed through the lower half of the field. What a spectacular view!"

Although at press time ASTRONOMY had received few observations of three other bright comets, these comets promised to keep observers busy throughout the autumn and winter of 1987. On August 21, Massachusetts observer Mike Rudenko found a magnitude 9.5 comet that was designated 1987u. Comet Rudenko passed perihelion on October 9, and three weeks later had brightened to magnitude 7.5 in the morning sky. Observers who rose early and searched in Leo found Rudenko had a short tail visible in binoculars.

David Levy of Tucson, Arizona, discovered his third comet on October 11. Past perihelion at discovery, Comet Levy (1987y) shone at magnitude 9 and slowly faded to 10th-magnitude by late October. The comet also slipped toward the horizon in the early evening sky, which made observing it difficult.

On photographs made just a week after Levy's discovery, Australian astronomer Rob McNaught found another 9th-magnitude comet, Comet McNaught (1987$b_1$). This comet rose in brightness to 8th magnitude by late October and would pass perihelion on December 11. Comet McNaught was discovered deep in the southern sky, but throughout October and early November it moved rapidly northward.

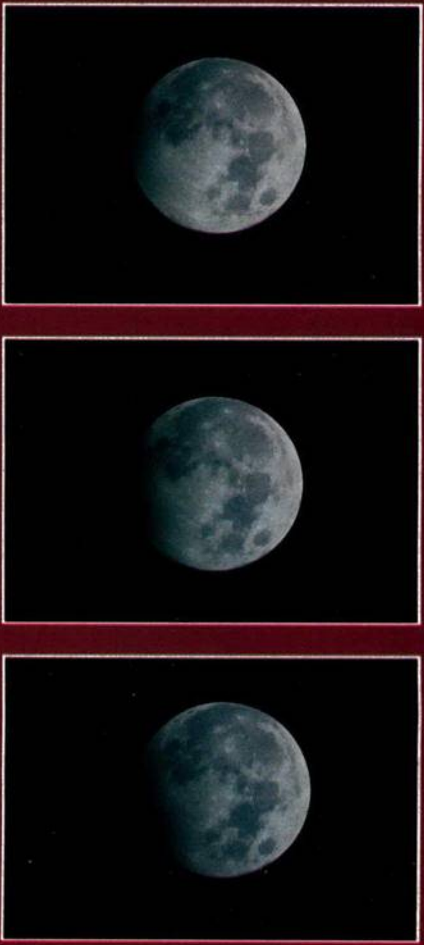
**October 7 Penumbral Lunar Eclipse.** Earth's shadow swept across the Moon beginning just before 01h UT on October 7, to create the second and last of 1987's penumbral lunar eclipses. "On the night of October 6, 1987, at about 8:15



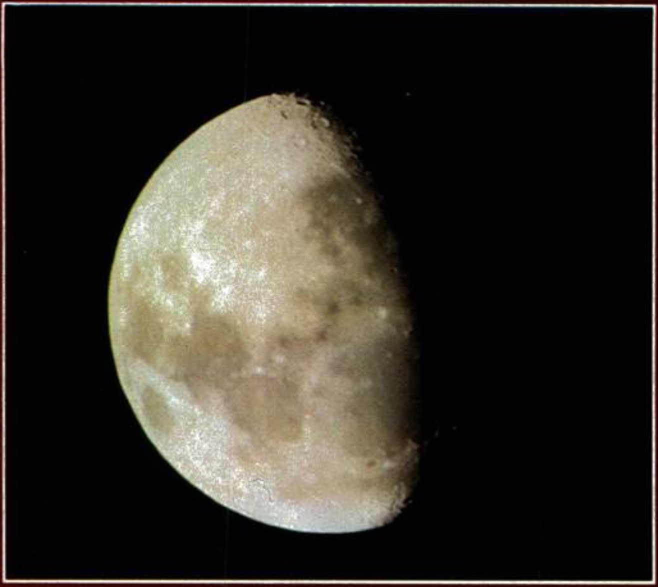
Above: Comet Bradfield faintly shows a 1°-long dust tail and 2°-long ion tail in this exposure made on October 22, 1987. Howard Brewington used an 8-inch f/1.5 Schmidt camera, hypered Tech Pan film, and a 5-minute exposure to capture the comet and M10. Brewington's exposure began half an hour after the sketch on the opposite page was finished.

Below: During mid-October 1987 Comet Bradfield's inner coma was exceptionally bright. At this time the comet was visible in 7x50 binoculars and had developed a tail. Bob Keller of Washington, Michigan, photographed Bradfield's inner coma with an 8-inch f/6 Newtonian and a 5-minute exposure on Kodak Professional 800/1600 ISO film.

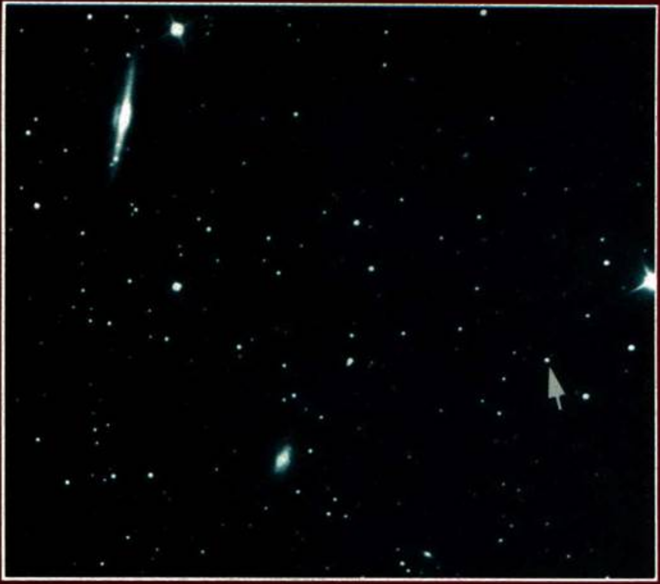
Less detailed and fainter than Comet Bradfield, Comet Levy was nonetheless visible in binoculars and small scopes, glowing at about 10th magnitude in mid-October 1987. Geoff Chester photographed Comet Levy from Rixeyville, Virginia, on October 16, with a 5.5-inch f/3.6 Schmidt-Newtonian, hypersensitized Tech Pan film, and a 10-minute exposure.



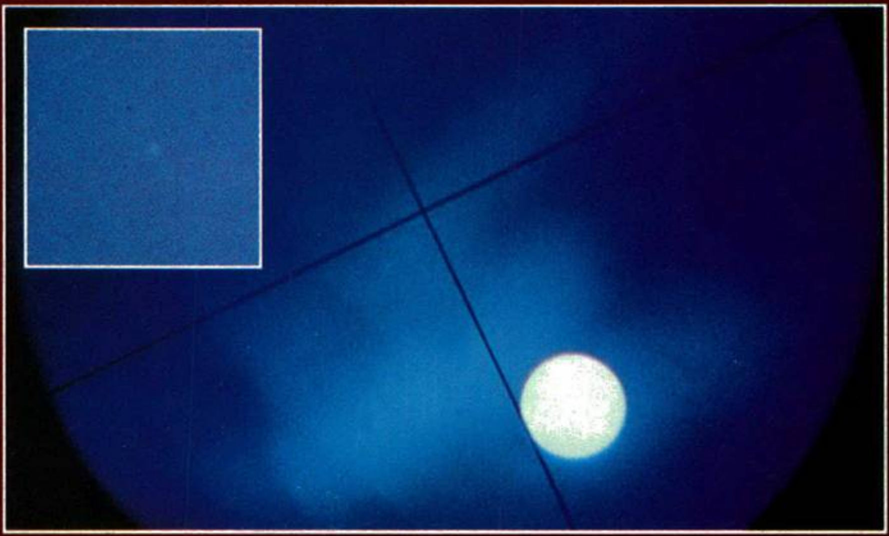
A penumbral lunar eclipse on October 6/7, 1987, attracted dozens of astrophotographers. Willy Groebner's series of photographs shows Earth's shadow progressing over the southeastern part of the Moon on October 6, from 10:18 p.m. CDT (top) to 10:43 p.m. (center) to 11:01 p.m. (bottom). Groebner used a 5-inch f/10 SCT, 400 ISO film, and 1/250-second exposures for each of the photographs.



On August 5, 1987, the Moon occulted Antares for viewers in southwestern Africa and the south Atlantic. With an 8-inch f/10 SCT and 200 ISO film Charles Stevenson of Cape Town, South Africa, photographed the pair moments before the Moon's dark limb passed in front of the bright star.



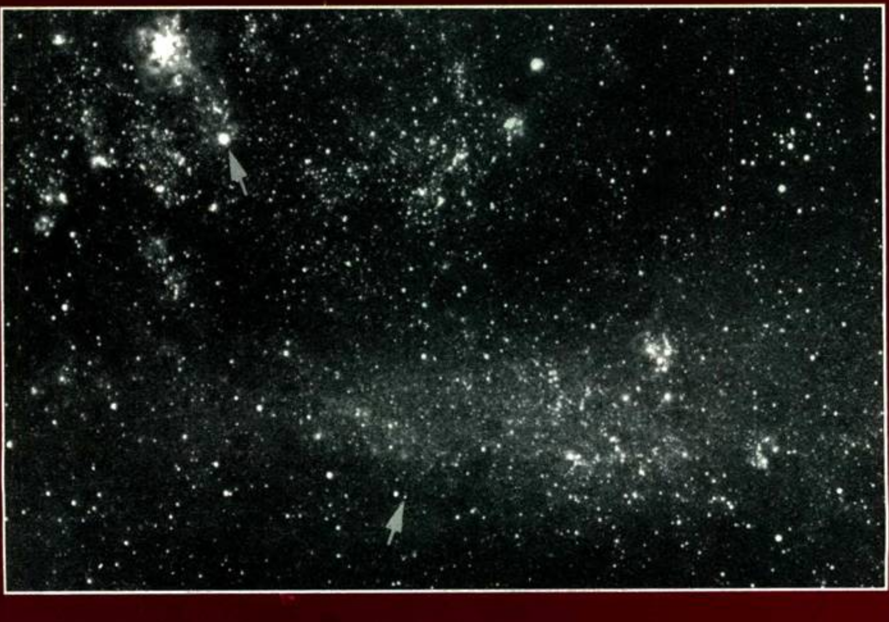
Throughout 1987 Pluto was easier than usual to find because it traced a retrograde loop between galaxies NGC 5746 (top) and NGC 5740. Pluto (arrow) glowed dimly at magnitude 13.8. Photo by Martin C. Germano, who used an 8-inch f/5 Newtonian, hypered Tech Pan film, and a 40-minute exposure.

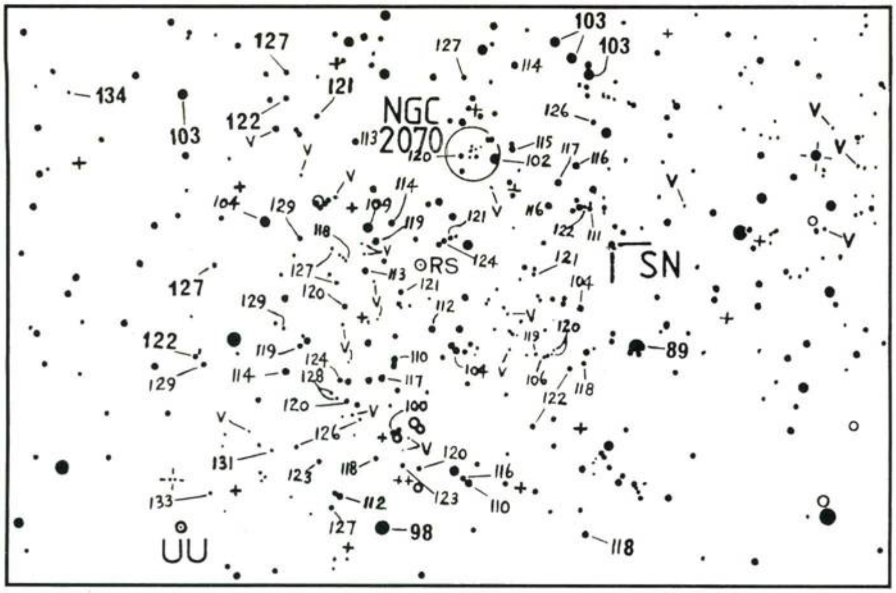


Left: Venus is bright enough to photograph and view during the day, but normally only when it lies far from the glare of the Sun. However, on August 22, 1987, Reginald Poole of Richmond, British Columbia, succeeded in photographing Venus only 9.5 hours before superior conjunction, when the planet was a mere 1.25° away from the Sun's limb. Poole covered his finder scope with mylar solar filters and photographed Venus' position.

Inset: Afterward Poole photographed the barely visible disk of Venus through his 8-inch SCT, which was stopped down to 3 inches in aperture and fitted with a mylar filter.

Right: Less than five months after Ian Shelton's discovery of Supernova 1987A in the Large Magellanic Cloud, Australian observer Gordon Garradd found a magnitude 9.5 nova in the LMC. Garradd's photo shows the nova at bottom right (arrow), the supernova (arrow), and the Tarantula Nebula at upper left. Garradd used a 300mm f/4.5 lens, hypersensitized Tech Pan film, and a 15-minute exposure.





**Mati Morel of the Royal Astronomical Society of New Zealand made this finder chart for Supernova 1987A (marked "SN") in the Large Magellanic Cloud. Magnitudes for comparison stars are given in tenths and variable stars are marked with a "V".**

p.m. MDT I set up outside and brought my 7x35 binoculars and two cameras," wrote Michael J. Hutchinson of Longmont, Colorado. "At 8:32 p.m. I detected the penumbral darkening in my telescope and binoculars but doubted it somewhat until 8:45 p.m., when it was obvious. At mid-eclipse, about 10:02 p.m., I saw the lunar disk darkened considerably on the Moon's southern side." The eclipse ended just after 6h UT on the 7th, having lasted slightly over five hours.

**Occultation of Antares**. The Moon travels around the ecliptic once per month, so occultations of the bright stars lying along the plane of the ecliptic aren't uncommon. The Moon occulted Antares on August 4, 1987. The occultation was centered on 23h UT on the 4th, and was visible in the south Atlantic and southwestern Africa. Charles Stevenson of Cape Town, South Africa, photographed the event "just before the dark side of the Moon passed in front of Antares at about 2:20 a.m. local time." In various parts of the world Antares was occulted by the Moon a total of twelve times during 1987.

**Pluto Passes Two Bright Galaxies**. Pluto became a favorite astrophotographic target last year as the 14th-magnitude dot of light made a retrograde loop between two bright galaxies in Virgo. The galaxies are NGC 5746, a magnitude 10.6 edge-on spiral, and NGC 5740, a small, 12th-magnitude spiral. The galaxies are reasonably well-known targets for deep-sky observers with large telescopes, so last season saw interested stargazers looking for both galaxies and a faint planet in this area of sky. An 8-inch telescope under a dark sky was generally the minimum required to see all three objects.

**Photographing Venus near the Sun**. Venus is extremely bright viewed in a dark sky, but when it lies near the Sun, it is exceedingly difficult to spot because of sunlight scattered by Earth's atmosphere. Last August 22, Reginald J. Poole of Richmond, British Columbia, nevertheless photographed Venus as it lay barely more than two Sun-diameters away from the Sun. Poole knew Venus would undergo superior conjunction, moving directly behind the Sun. Nine-and-a-half hours before the conjunction took place, at 1:30 p.m. PDT, Poole attempted to photograph Venus when it lay only 1.25° away from the edge of the Sun's disk.

Poole used an 8-inch f/10 SCT stopped-down to 3 inches in aperture to reduce glare from the Sun. He first photographed the position of Venus relative to the Sun with a finder scope. Then Poole spotted Venus in the main telescope and photographed the planet's faint image.

**Supernova 1987A**. Ever since its discovery on February 24, 1987, astronomers in the Southern Hemisphere have closely monitored Supernova 1987A in the Large Magellanic Cloud. Shining at magnitude 4.5 on the night of its discovery, the supernova reached peak brightness on May 20, 1987, at magnitude 2.9. It has slowly faded ever since, having dropped to magnitude 5.4 by the end of October 1987. Given the supernova's slow drop in brightness, backyard astronomers in the Southern Hemisphere will be able to observe Supernova 1987A for several months to come. Who will be the last to see the supernova as it slips below the range of backyard telescopes?

Anticipating lots of interest in watching Supernova 1987A fade, New Zealand variable star observer Mati Morel has produced a finder chart that shows the supernova's position and magnitudes of comparison stars all across the Large Magellanic Cloud. "The chart is suitable for following the supernova down to 12th magnitude," Morel writes. "I have prepared it using photoelectric V magnitudes for the comparison stars rounded off to tenths. The sequence is being used by members of the Variable Star Section, Royal Astronomical Society of New Zealand."

**Nova in the Large Magellanic Cloud**. As if a supernova weren't enough activity in the Large Magellanic Cloud, observer Gordon Garradd of New South Wales discovered a nova in the LMC on plates made September 21, 1987. The nova lies only 1.25° from the LMC supernova and shone at magnitude 12 when it was discovered. Checks on plates made three and four days earlier revealed that the star had been as bright as magnitude 9.5.

Garradd sent ASTRONOMY the details of his discovery. "Rob McNaught and I have had our second nova discovery in the Magellanic Clouds in one year of photographic patrolling. Rob picked his up in the SMC in December 1986 about two months after maximum with an 85mm f/1.2 Canon lens and Tri-X film." Since that discovery Garradd had been eager to find a nova himself.

"I photographed the LMC on September 15, and searched the photo the following day. It was quite a deep photo and recorded stars down to about 15th magnitude. I found a couple of variable stars but no nova candidates. On the 17th, I made another photo of the clouds, finishing off the roll of Tech Pan film. I thought the developer was a bit old, so I mixed some fresh solution at about midnight. Unfortunately, unknown to me until I used it, I mixed the HC-110 developer incorrectly and made a super strong brew guaranteed to rip the emulsion off of any roll of film.

"I discovered this was the case when the developed film resembled the inside of a black hole. I diluted the overly strong developer and hoped the next batch of photos would show something.

"So I made some more photos of the Clouds on September 21, but for some reason left my negatives hanging to dry for two-and-a-half days. When I finally checked them on the afternoon of the 24th, I found an image at about 12th magnitude on two photos made on the 21st but not on a comparison photo made on July 31. I then called Rob McNaught and had him confirm that a star normally did not belong at that position. He checked the situation and before I knew it, I had discovered a nova."

*— David J. Eicher*

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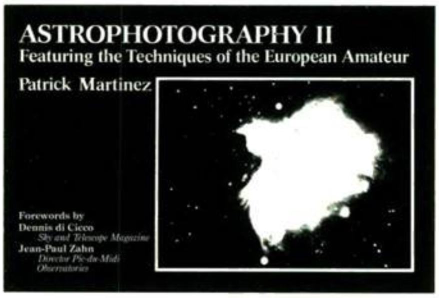
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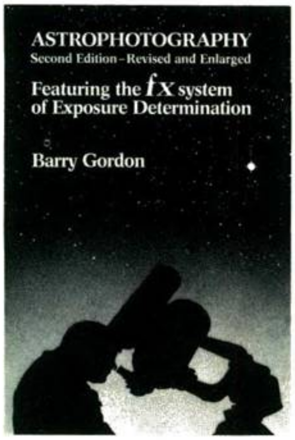
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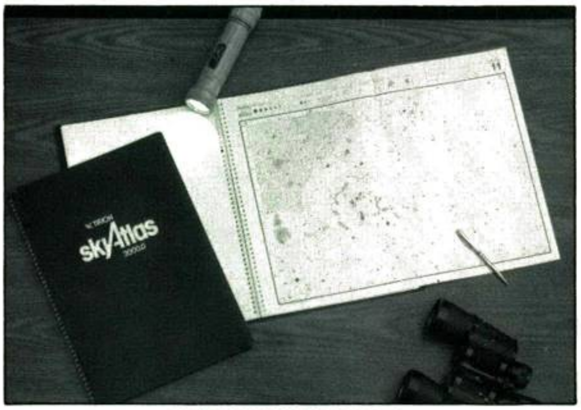
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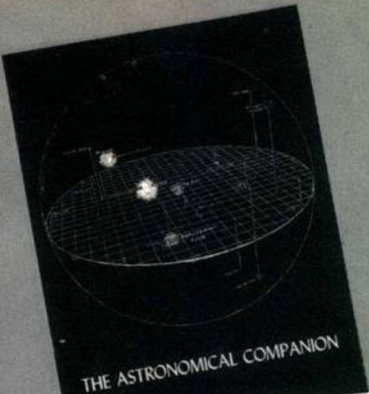
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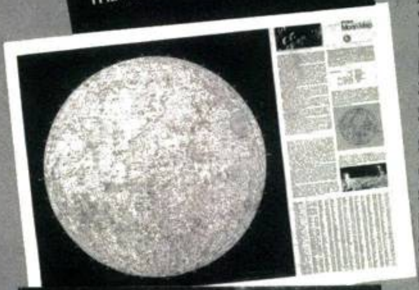

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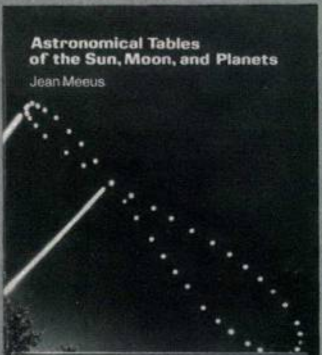
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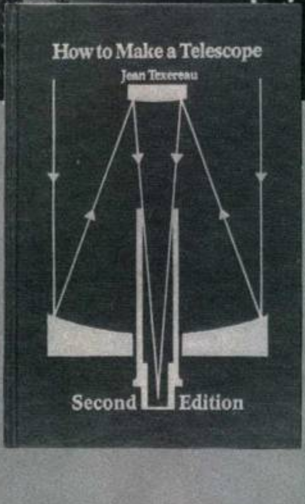
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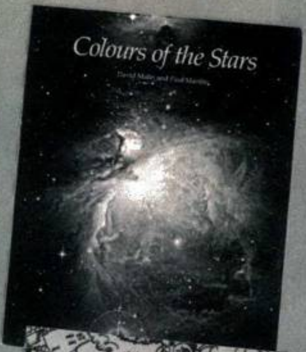
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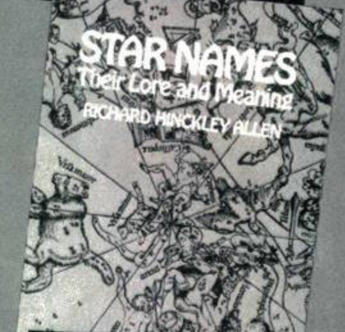
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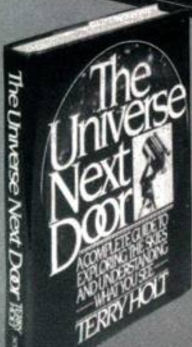
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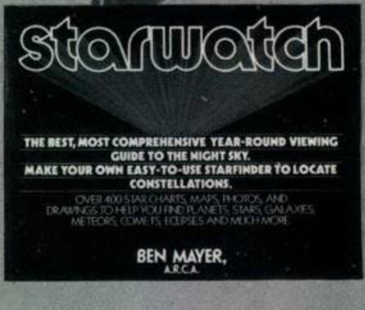
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## Our Cosmic Horizons

# Part One: From the Cradle of Creation

by Robert Scherrer

*Cosmology seeks answers to the most fundamental questions about the nature of the universe. In the four-part series, Our Cosmic Horizons, ASTRONOMY explores key areas of cosmological research and how that research is contributing to our knowledge of the universe.*

*Part one looks at the origin of the universe and how conditions created in the Big Bang could have shaped the universe we see today. Part two reports on the search for dark matter and the implications of dark matter on the expansion of the universe. Large-scale structures in the universe is the subject of part three, and the computer modeling of structures in the universe appears in part four.*

Let's design an experiment to test certain theories about the way gravity operates in the universe. Instead of setting up the experiment in a convenient laboratory, we will scatter the experiment over many different places, separated by a billion trillion miles. Although hard-working scientists usually check on the progress of their experiments every day, we won't. Instead we'll set our experiment in motion and check on it later — perhaps 10 billion years later.

The scientific method also requires that an experiment be repeated, preferably many times, to verify results. However, our experiment is too elaborate to perform more than once. I don't mean once in our lifetimes or once a millennium; just once, ever.

This "experiment" is the evolution of the universe. The scope gives some idea of the difficulties facing those who try to explain the large-scale structure of the universe. We take it for granted that the universe contains galaxies, stars, planets, and people. And yet there is no good physical explanation for why any of these concentrations of matter should exist. One of the major problems with the Big Bang theory is that this theory cannot explain how matter built up from atoms to sizable chunks of material in a rapidly expanding universe.

So why do galaxies exist? Evidence indicates the answer might be found in the conditions that existed at the birth of the universe, when temperatures, pressures, and densities were far beyond what can be created in a laboratory, and bizarre physical processes that can only operate in such an environment might have given rise to much of what we see today.

### A Lumpy Tightrope

Before journeying all the way back to the beginning of time, we need to understand the role gravity plays in the structure of the universe. Isaac Newton's theory of gravitation explained the force of attraction between objects: every body attracts every other body with a force proportional to the respective masses of the bodies. Gravity, Newton realized, was a force that could explain the motions of bodies in the solar system as well as of objects on Earth. Today we recognize that gravity affects the movement of matter over distances that span the universe.

Suppose you set up an expanding box in space, full of stars all flying away from one another, and you were very careful to make sure the stars were evenly distributed throughout the box. Each star would feel the gravitational pull of all the other stars, and the stars would be pulled equally in all directions; hence, the trajectory of the stars would remain unchanged.

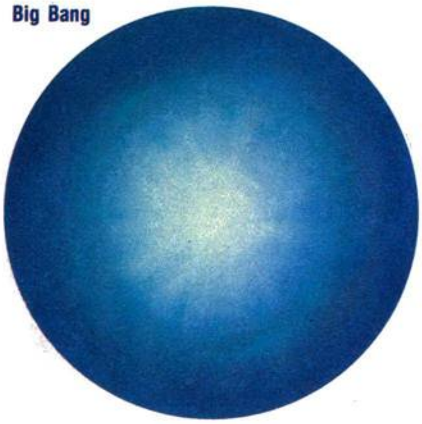
But now suppose you were somewhat careless when you put the stars in the box, and you distributed them unevenly so one corner of the box contained a few too many stars. The greater number of stars in that corner would exert a larger gravitational force than other parts of the box, attracting the other stars, and upsetting the distribution even further. The gravitational force exerted by the mass accumulating in that corner of the box would grow, attracting still more stars.

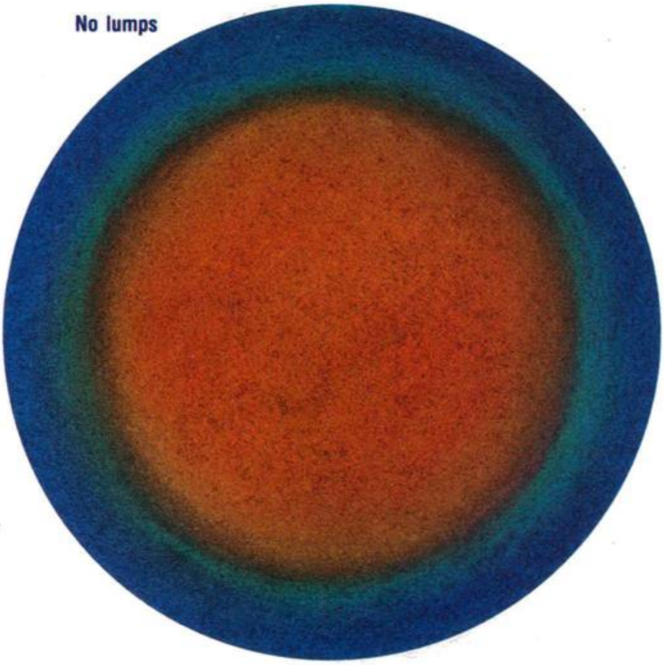
Gravity, then, makes the universe unstable. Matter that is smoothly distributed is not altered by gravity, because gravity acts equally on that matter in all directions. But even a tiny excess of mass in one region is enormously amplified by gravity.

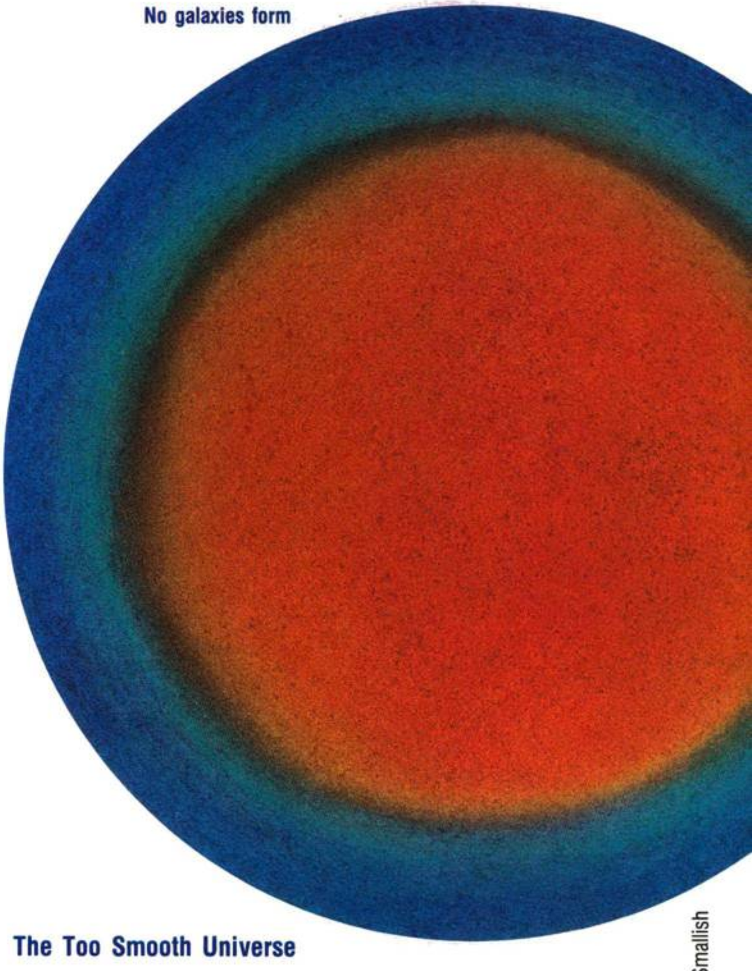
This idea remains the foundation for most modern theories and explains the large-scale structures in the universe. The problem is that it works too well. If in our attempts to model the early universe we put reasonably sized irregularities in the matter, these irregularities would grow into extremely dense regions today, much denser than any region of the universe we can see. These regions would grow so dense, in fact, that they close off space itself by turning into black holes. Nevertheless, we can calculate how irregular the early universe must have been, based on how lumpy the universe is today, and if we can estimate the age of the universe, we can determine how much time these lumps had to grow.

It turns out that to produce the lumpy universe we see today, the distribution of matter must have once been *almost* completely smooth. Some regions of space had more matter than others, but only by a tiny amount of about one part in 10,000. To get an idea of how small this is, imagine a row of dogs, some with a single dollar bill on their backs and some without. The difference in weight between the dogs with the dollar bills and those without is the same difference we need in different regions of the early universe.

This, then, is the paradox: The universe couldn't have started out completely smooth, or it would have stayed completely smooth and we *wouldn't* have ended up with galaxies, stars, planets, and people. On the other hand, if matter in the universe had started out too lumpy, these lumps would have grown enormously by now, probably







### The Too Smooth Universe

**Galaxies and galaxy clusters do not form in a universe where matter is too smoothly distributed. Gravity acts equally in all directions, and no disturbances occur to increase the density in local areas of the universe. Thus, no gravitational field is created to attract matter, and the universe expands smoothly.**

Illustrations by Craig Smallish

turning into massive black holes that could swallow up all the matter and our chances for existence. The universe we live in walks a tightrope between these two fates.

### Physics at the Breaking Point

How could the universe have started out almost completely smooth? This is the mystery. But theories of the early universe are beginning to provide a few possible answers.

For example, by running the expansion of the universe backward like a movie, we learn that conditions in the early universe were very different from what we see today. The universe becomes more dense and radiates at increasingly higher temperatures the farther back in time we go. On a terrestrial scale the universe is like the air in a piston. When compressed in a piston, air heats up; when it expands, air cools off. Right now the universe is expanding, and as the universe expands, it cools. Today the radiation left over from the Big Bang is so cold it cannot boil liquid air, and it is barely detectable from the surface of the Earth. However, as we run the expansion of the universe backward, the universe contracts, and as it contracts, the universe heats up.

Five hundred thousand years after the Big Bang, when the temperature of the contracting universe reaches 4,000 kelvins — equal to the temperature of a cool star — collisions between atoms are violent enough to tear electrons from their nuclei, and matter is ionized. The radiation in the universe at this temperature is mostly in the form of visible light. But rays of light cannot travel very far in an ionized gas because of frequent collisions with free electrons, so the universe is actually opaque. By the time the contraction raises the temperature of the universe to a million degrees — between five and ten years after the Big Bang — this radiation turns into x-rays.

Fifteen seconds after the Big Bang the temperature is several billion degrees, much hotter than the temperature at the center of the Sun. The forces that hold atomic nuclei together are overwhelmed, fragmenting the nuclei into protons and neutrons. By now the average density of the contracting universe is greater than the density of lead.

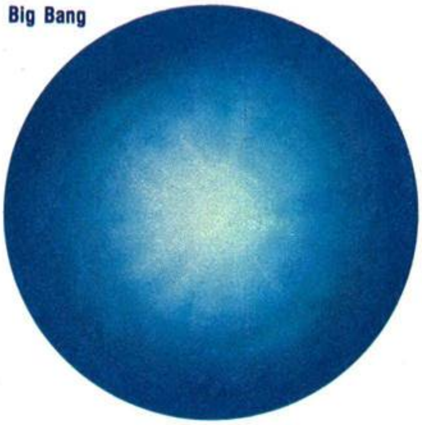
About 1/10,000th of a second after the Big Bang the temperature of the universe is a trillion degrees, hotter than a supernova core. The radiation maelstrom produces exotic particles such as muons (a type of "heavy electron" seen today only in cosmic-ray showers and powerful accelerators), and the protons and neutrons themselves fragment into their constituent parts, called quarks. Matter as we know it ceases to exist, yet we are not even close to the temperatures needed to explain the origins of galaxies and galaxy clusters.

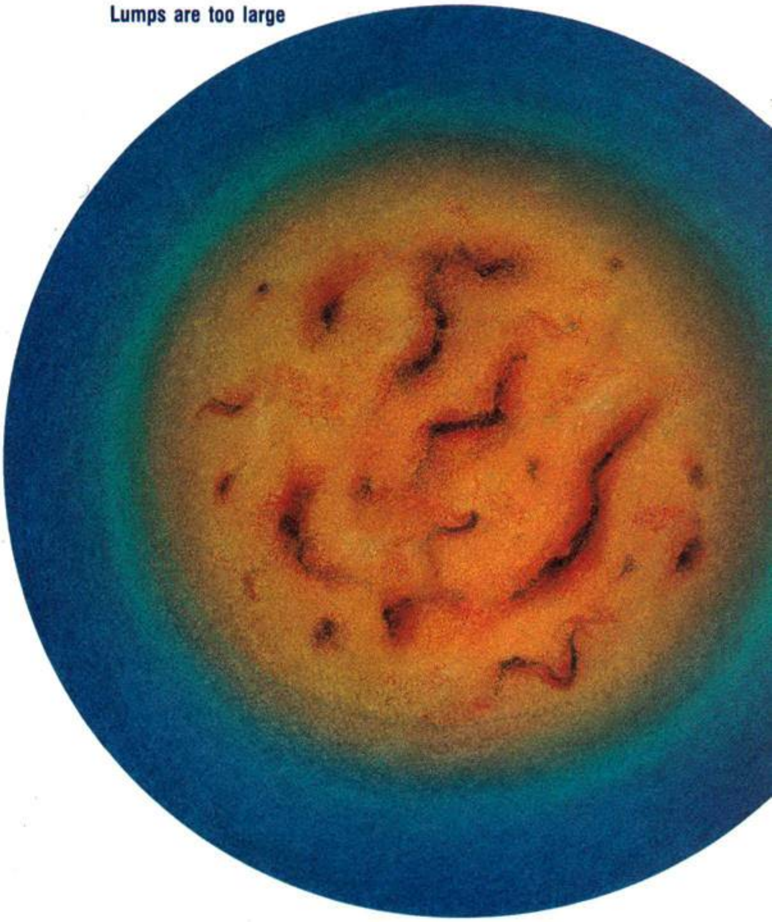
Unfortunately the laws of physics as we know them at ordinary temperatures begin to break down at a temperature of about 100 million trillion trillion degrees, which is thought to be the temperature of the universe

$10^{-43}$ of a second after the Big Bang. This particular era in the history of the universe is referred to as Planck time, named for Max Planck, a German physicist who was one of the pioneers of quantum mechanics. To understand why the laws of physics break down, we need to examine the two great achievements of twentieth century physics: the theory of relativity and quantum mechanics.

By the turn of this century phenomena had been discovered that simply couldn't be explained by Newton's theory of gravitation, such as how gravitation affected space and time in the vicinity of extremely massive objects. Although Albert Einstein's general theory of relativity resolved these problems, it went far beyond that, predicting such exotic phenomena as black holes, the gravitational bending of light, and the expansion of the universe itself. Relativity has barely been altered since Einstein developed it: as far as physicists can test it, his original theory exactly describes the way gravitation operates.

Quantum mechanics was also developed to patch up a theory that wasn't working quite right: in this case the way a hot object emits radiation. Quantum mechanics provided an explanation for the structure of the atom and the behavior of the atomic nucleus, and it led to the development of semiconductors, which are used in manufacturing small electronic circuits in computers among other things. Today quantum mechanics provides the basis for much of modern physics.





**The Too Lumpy Universe**

**Excessive irregularities in the distribution of matter in the early universe attract too much matter in certain regions of space. These regions become extremely dense and eventually collapse into supermassive black holes that swallow up all matter.**

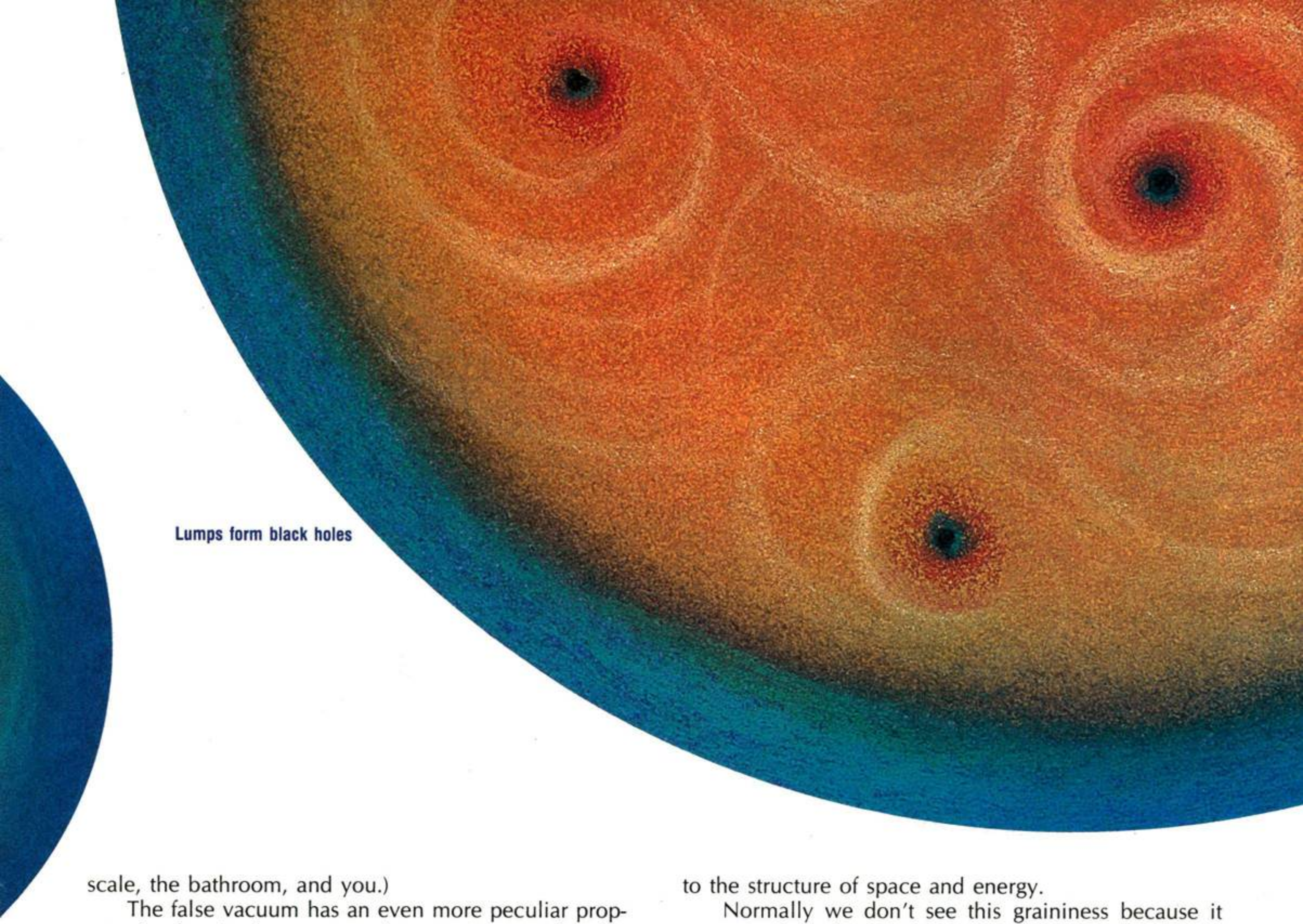
Relativity and quantum mechanics, however, address the behavior of matter at different scales. Relativity deals with the attraction between massive objects, such as stars and planets, while quantum mechanics is concerned with the behavior of subatomic particles. A description of the behavior of the universe at the enormous temperature mentioned above (called the Planck temperature) requires a *unified* theory of gravitation and quantum mechanics, one that takes into consideration the effects of quantum mechanics on gravitation. Einstein tried to develop such a theory and failed; many have followed in his footsteps. Such a theory remains the greatest unsolved problem in modern physics.

At the Planck temperature ($10^{32}$ degrees), quantum mechanics and relativity begin to make absurd and contradictory predictions. For example, they predict that particles of light themselves would collapse into miniature black holes. This doesn't mean the temperature of the universe could never have been that high but that we have no idea of what would happen at such high temperatures. We will have to confine our attention to temperatures below 100 million trillion trillion degrees. Still, this provides considerable room for maneuver.

### The Bizarre Behavior of Space Itself

The key to understanding how the seeds for the large-scale structure of the universe might have originated $10^{-43}$ second after the Big Bang lies in the nature of space itself: the vacuum. At temperatures not too far below the Planck temperature the vacuum has some very interesting properties. We generally think of a vacuum as just empty space, but modern physics has shown that the vacuum is actually seething with activity. Even at the temperatures encountered in our everyday experience, particle and antiparticle pairs are continuously popping out of the vacuum and disappearing again. Physicists have actually detected this phenomenon in the laboratory; it is not simply the musing of someone's overactive intellect.

At higher temperatures the vacuum behaves in an even more bizarre way. It seems obvious that a vacuum must be completely empty, yet at a high enough temperature the vacuum itself can acquire a mass. As a concession to our sensibilities, physicists have named this sort of vacuum the "false" vacuum, but it is a vacuum nonetheless, and one you could weigh on your bathroom scale if you had a sample of it in a bottle. (Of course, this sort of vacuum can exist only at very high temperatures, so the bottle would be vaporized, along with the bathroom



Lumps form black holes

scale, the bathroom, and you.)

The false vacuum has an even more peculiar property: its density does not go down as it expands. This seems absurd because everything gets less dense as it expands. Imagine a piece of taffy that doesn't get thinner as it is pulled; instead more taffy is spontaneously created in the space where you are pulling, so the density of the taffy is constant. This is precisely the way the false vacuum behaves. If the false vacuum is stretched, more energy is created to fill the empty space and keep the density constant.

Where does this energy come from? Again let's return to the analogy of the piston. When the air in a piston expands, it exerts pressure on the piston, which performs work and causes the energy in the air to decrease. But the false vacuum exerts a *negative* pressure: when the false vacuum expands, it performs negative work, which causes energy to flow into it.

As you might imagine, a universe containing a false vacuum behaves in a very strange way. Such a universe has a constant density even as it expands, and the false vacuum provides a "runaway" expansion. The universe inflates like a gigantic balloon; hence, this theory is called inflation.

### What Caused the Nonuniformities?

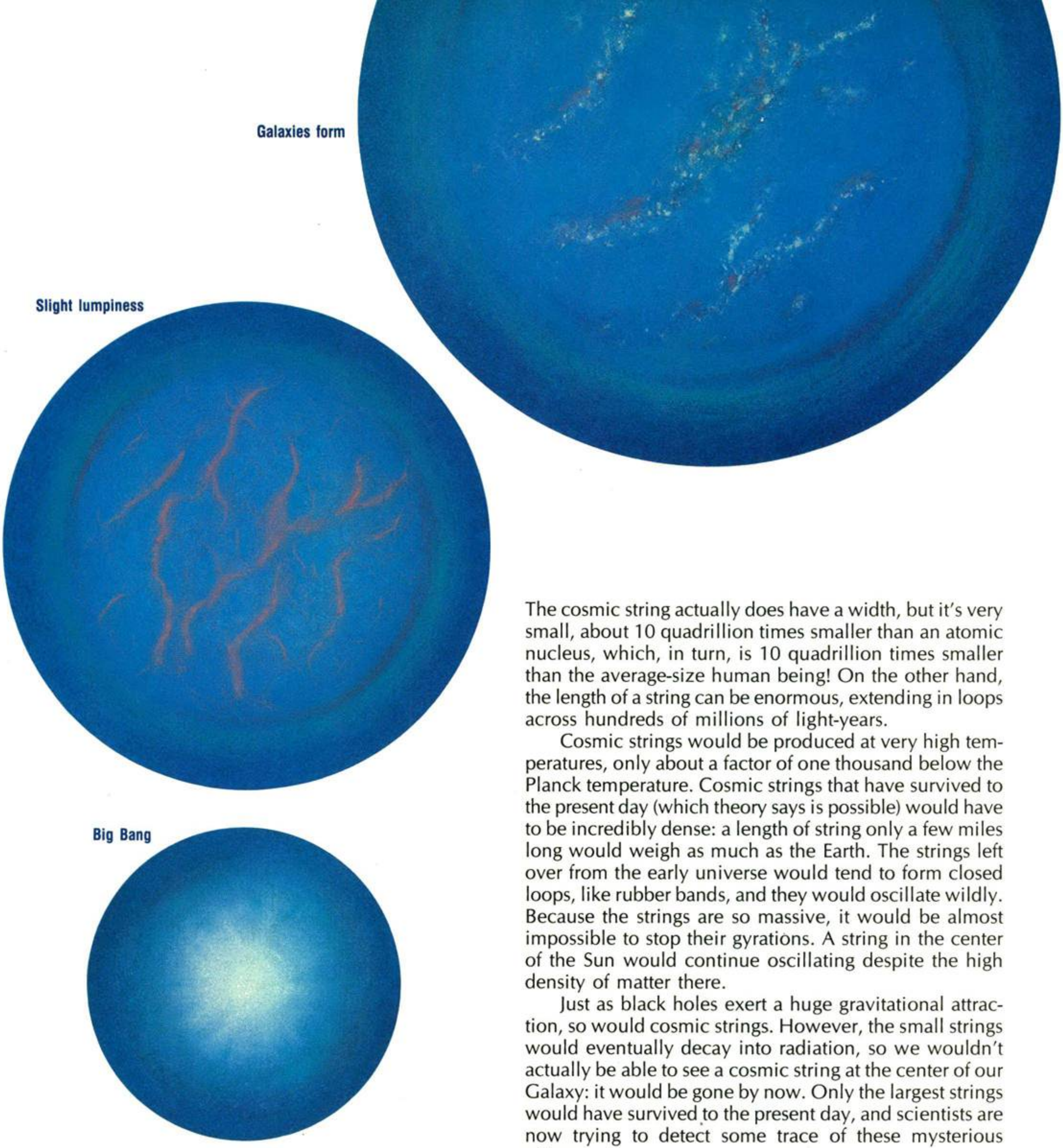
Unfortunately, if the universe started out perfectly smooth, inflation could not generate the density fluctuations that later spawned the galaxies. However, the universe is never perfectly smooth at the submicroscopic level. One of the revolutionary ideas of quantum mechanics is that there are always tiny fluctuations in energy density on very small scales. These tiny fluctuations aren't produced by any outside force: they are simply intrinsic to the structure of space and energy.

Normally we don't see this graininess because it occurs only at the submicroscopic level. But if inflation occurs, its effects blow up these fluctuations by a tremendous factor until the fluctuations are large enough to produce galaxies and larger structures. There are still some problems with the inflation theory: the simplest version of the theory produces density fluctuations that are far too large, but it remains a very promising approach and is under intense investigation.

A less esoteric way to introduce density fluctuations into the universe would be to postulate some sort of objects left over from the early universe. Matter would be attracted by the gravitation of these objects and collect around them to form the clusters and superclusters of galaxies we see today. The earliest theory of this type was based on black holes, concentrations of matter so dense that even light cannot escape from them. Massive black holes might be copiously produced in the high density of the early universe, or they could form from the collapse of an early generation of massive stars. Although matter could collapse around black holes to form galaxies, the black holes in these galaxies would also exert huge tidal stresses that distort or possibly rip a galaxy apart into its constituent stars.

Moreover, black holes also aren't perfectly "black." In 1974 Stephen Hawking showed that black holes actually have a temperature and are gradually radiating away their mass. Hence, a black hole that formed during the Big Bang should give off detectable radiation. But we have not detected any radiation that might have been left over from these evaporations.

Another theoretical explanation for the cause of den-



**The Just Right Universe**

**For galaxies to form, the distribution of matter in the universe must start out nearly completely smooth, except for some regions that are slightly higher in density than other regions. These denser regions attract just enough material to collapse into filaments of galaxies, within which form stars, planets, and people.**

sity fluctuations calls for an even more bizarre relic of the early universe: cosmic strings. If they exist — and if we had the means to see them — cosmic strings really would look stringlike. An elementary particle has no dimensions: it resembles a point and has no extension in any direction. A cosmic string is the next step up from this: it has one dimension and resembles a line rather than a point. The cosmic string actually does have a width, but it's very small, about 10 quadrillion times smaller than an atomic nucleus, which, in turn, is 10 quadrillion times smaller than the average-size human being! On the other hand, the length of a string can be enormous, extending in loops across hundreds of millions of light-years.

Cosmic strings would be produced at very high temperatures, only about a factor of one thousand below the Planck temperature. Cosmic strings that have survived to the present day (which theory says is possible) would have to be incredibly dense: a length of string only a few miles long would weigh as much as the Earth. The strings left over from the early universe would tend to form closed loops, like rubber bands, and they would oscillate wildly. Because the strings are so massive, it would be almost impossible to stop their gyrations. A string in the center of the Sun would continue oscillating despite the high density of matter there.

Just as black holes exert a huge gravitational attraction, so would cosmic strings. However, the small strings would eventually decay into radiation, so we wouldn't actually be able to see a cosmic string at the center of our Galaxy: it would be gone by now. Only the largest strings would have survived to the present day, and scientists are now trying to detect some trace of these mysterious objects.

### The 'Critical Density' Question

Astronomers suspect the visible structure of the universe is only the skeleton of the total universe. In the last decade, studies of the movements of galaxy clusters as well as the rotational velocities of stars in galaxies have shown that the visible part of the universe is being influenced by "hidden" matter. In a profound way, scientists are no longer certain about what the universe is really made of.

As we will see, this uncertainty hinges on one of the deepest questions in cosmology today: Will the universe expand forever, or will it someday begin to contract and ultimately collapse into a "big crunch"? The answer to this question depends on the density of the universe.

We can think of the expansion of the universe as something like a rocket attempting to escape Earth's gravity. If the velocity of the rocket is above the "escape velocity" of the Earth (several miles per second), then the rocket can escape Earth's gravity. On the other hand, if the velocity is below this escape velocity, then the rocket will gradually slow down and ultimately crash back into the Earth.

The universe has an escape velocity too. If all the matter in the universe is moving faster than this escape velocity, then the universe will expand forever, but if the velocity of the matter is too low, then the universe will collapse back on itself.

Astronomers can easily measure the precise velocity at which the universe is expanding, but we don't know the "escape" velocity of the universe, because that depends on the density of the universe. The greater the density of the universe, the harder gravity pulls on the expanding matter and the faster matter must move to escape collapse. A high-density universe must ultimately collapse back into a "big crunch," but a low-density universe can expand forever. Between these two states is a "critical density," at which the expansion just balances the gravitational attraction of matter in the universe. If the density is below the critical value, the universe will expand forever, but if the density is above it, the universe will ultimately collapse.

In principle, then, all we need to do is measure the density of the universe, compare it with the critical density, and we can determine the fate of the universe. This method would work fine if we were sure we were seeing *all* the matter in the universe. As mentioned earlier, though, astronomers believe there is a great deal of matter in the universe we cannot see. We can, however, indirectly measure the density of the universe by determining the abundances of various elements and working backwards to calculate how dense the universe had to be to produce those elements.

Most of the elements on Earth — the carbon, nitrogen, and oxygen that make up our bodies, and the various metals contained in the Earth's crust — were produced in the centers of stars by fusing hydrogen into progressively heavier elements. However, it looks as though helium and deuterium (the latter is a form of heavy hydrogen with one neutron in the nucleus) were produced when the universe cooled to about a billion degrees, in much the same way other elements are produced in stars.

At very high densities and temperatures, protons and neutrons fuse together to form heavier nuclei. About 25 percent of the hydrogen in the early universe was fused into helium with a small remnant left behind as deuterium. (Deuterium is produced from the incomplete fusion, or "burning," of hydrogen into helium; it is the carbon monoxide of the early universe.) However, the exact amount of deuterium and helium produced depends on the density of the universe. Based on this method, it turns out that the density of the universe is far below the critical density. If this is correct, gravity will not win out over the expansion velocity, and the universe will expand forever.

### Is That All There Is?

Still, it may be premature to assume the universe will expand forever. For example, the inflation theory predicts that the density of the universe should be almost exactly equal to the critical density. Usually, such a blatant contradiction would spell the end of any theory. However, there is strong evidence that we aren't seeing all of the matter out there. In fact, what we see may comprise only 5 to 10 percent of the entire universe.

We know the mass and brightness of our own Galaxy. By comparing that amount with the total amount of light emitted by all of the objects in the universe, we can derive one measurement of the total density of the universe. Another more direct way of measuring density is to observe how galaxies behave under the influence of gravity, because the gravitational force exerted by an object depends on its mass.

But these two ways of measuring the density of the universe give contradictory answers. The density derived from the observed light in the universe is much lower than the density observed from the gravitational interactions of objects giving off the light. The obvious conclusion is that there must be some sort of hidden matter that is not radiating visible light. This matter has been aptly named dark matter.

The nature of dark matter is enigmatic at best and has spawned a number of theories about what it might consist of. The first candidate for dark matter was the neutrino, first detected after World War II when nuclear reactors started producing energy. Neutrinos are ghostly particles that barely interact with ordinary matter. A neutrino would pass through millions of miles of lead without being stopped.

Although it is assumed that the neutrino has no mass, there is no reason to believe this must be the case. If the neutrino had a very small mass — less than one-thousandth the mass of the electron — then neutrinos would make up most of the mass of the universe in the form of dark matter.

Other particles have been suggested as the constituents of dark matter, but unlike the neutrino, none of them has ever been detected. These exotic suggestions include the axion, a particle with a tiny mass that simply pops out of the vacuum, and supersymmetry particles that are "mirror images" of the ordinary subatomic particles we observe but with much higher masses.

If dark matter really is composed of exotic particles, then there is no longer any simple relation between element production in the early universe and the total density of the universe. It is quite possible that the density of ordinary matter is low enough to produce the correct element abundances, while the density of the dark matter is high enough to cause the universe to collapse at some future time. In this case, matter as we know it — the matter comprising galaxies, stars, planets, and ourselves — makes up only a fraction of all the matter in the universe. Perhaps everything we observe is only a ghostly film floating on the dark matter of the universe like algae on the surface of a pond.

Dark matter could provide a density almost exactly equal to the critical density, as predicted by inflation. Inflation tells us that the density of the universe is just a little bit above the critical density value, or a little bit below it, but the difference is so small that it is almost indeterminable. In this case we might not be able to learn the ultimate fate of the universe, but at least it will give our descendants something to do.

Next month in the second part of Our Cosmic Horizons series Virginia Trimble discusses evidence for and against the existence of dark matter in the universe.

*Robert Scherrer is a postdoctoral research associate at the Harvard-Smithsonian Center for Astrophysics and the Harvard University Department of Physics in Cambridge, Massachusetts.*

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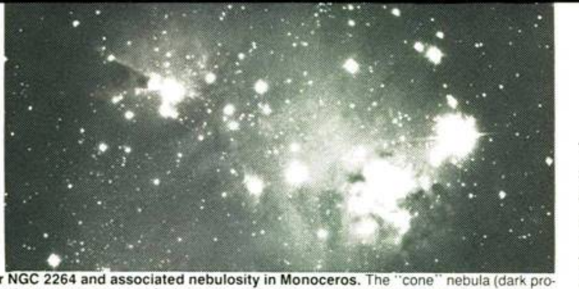
# LUMICON FOR HIGH PERFORMANCE

## ASTROPHOTO OF THE MONTH



**Open Cluster NGC 2264 and associated nebulosity in Monoceros.** The "cone" nebula (dark protrusion) is to the left and bright star S Monocerotis is to the right; north is to right. This nebulosity has very low surface brightness, and reliable visual sightings of the cone nebula are not yet reported; try a LUMICON H-Beta filter or a LUMICON Oxygen-III Filter. NGC 2264 is best photographed with a LUMICON DEEP-SKY Filter. Photo by Bill Sorrells, 16" f/5, hyper 2415 film, 40 minutes using a LUMICON 2" EASY-GUIDER™

## 20mm NAGLER

### Also new 12mm & 16mm NAGLERS

### TELE VUE™ EYEPIECES USE THE BEST!!

ALL IN STOCK

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|---|---|
| Renaissance 4" f/5.5. Telescope | $1395 |
| **7.4, 10.4, 13, 17, 21, 26mm Plossl,** 50° | $89 |
| **1.8X or 2.5X Tele Vue Barlow Lens** | $89 |
| **32mm Plossl,** widest true field in 1¼" | $109 |
| **55mm 2" Plossl,** widest possible field | $190 |
| **15mm Wide-Field,** 1¼" eyepiece, 65° | $129 |
| **19mm Wide-Field,** 1¼" eyepiece, 85° | $139 |
| **24mm Wide-Field,** "superb," 65° | $159 |
| **32mm Wide-Field,** 2" eyepiece, 65° | $229 |
| **40mm Wide-Field,** "awesome," 65° | $289 |
| **4.8mm Nagler,** 82° field | $149 |
| **7mm Nagler,** 1¼" eyepiece, 82° field | $185 |
| **9mm Nagler,** 82° field, "the best" | $219 |
| **11mm Nagler,** 82° field, 1¼" or 2" | $235 |
| **13mm Nagler,** 82° field, 1¼" or 2" | $249 |
| **12mm Nagler,** type II, 82°, 1¼"/2" | $249 |
| **16mm Nagler,** Type II, 82°, 1¼"/2" | $299 |
| **20mm Nagler,** Type II, 82°, 2" only | $340 |

## NEW! ENHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

**LUMICON 1.3" & 2.1" enhanced silver diagonal mirrors & 1¼" star diagonal.**
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave.

| | | | | | |
|---|---|---|---|---|---|
| 1.32" | **$29.95** | 1.52" | **$34.50** | 1.83" | **$39.50** |
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### ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

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| 1¼" (1.32" mirror) | **$89.50** |
| 2" (1.83" mirror)(see photo above) | **$145.00** |

## LUMICON FILTERS STOP LIGHT POLLUTION

## UHC Filter™

### ULTRA HIGH CONTRAST

The **LUMICON UHC FILTER** is specially designed for visual astronomy in areas of severe light pollution or for viewing very faint nebulae at any location. **UHC** stands for **U**ltra **H**igh **C**ontrast and this filter is guaranteed to yield a higher visual contrast on planetary and emission nebulae than any other filter at any price. 24nm visible bandpass, 482-506nm. Transmission = 85-95%.

**"I CAN SEE THE OWL NEBULA!"**
Tom Kramer saw the Owl Nebula, M-97, for the first time using a LUMICON UHC Filter. He stated, *"I had never seen M-97. . . I attached the UHC Filter and tried again. M-97 was right there. I could not believe it! The UHC Filter should be standard equipment."* **Tom Kramer, Sayville, NY**

For optimum astronomy, use either the **LUMICON DEEP-SKY Filter** or the **LUMICON UHC Filter**

### DEEP-SKY FILTER™

The **LUMICON DEEP-SKY FILTER** improves your view of **all** deep-sky objects including galaxies and comets. It removes natural and man-made light pollution and yields 3-6x contrast gain for nebulae and 1-3x contrast gain for clusters and galaxies. It is ideal for **both** visual use and B&W or color photography. This gentle filter yields the most natural view of any LPR filter available today. 90nm visible bandpass. 442-532nm. H-Alpha 656nm transmission = 85-95%. Visible transmission = 90-95%.

| | Standard | Premium* |
|---|---|---|
| **0.96" LUMICON DEEP-SKY Filter** threads into most 0.96" eyepieces | | $59.50 |
| **1¼" LUMICON DEEP-SKY Filter** threads into most 1¼" eyepieces | | $79.50 |
| **48mm LUMICON DEEP-SKY Filter** (1.75" aperture), threads into most 2" eyepieces. Also fits LUMICON EASY-GUIDERS | | $119.50 |
| **2" LUMICON DEEP-SKY Filter** (1.5" aperture), threads into most 2" eyepieces. Also has male & female camera T-threads for prime focus photography | $99.50 | $119.50 |
| **72mm LUMICON Giant DEEP-SKY Filter** (62, 67, 77mm adapter, $8) | | $299.50 |
| **1¼" LUMICON UHC Filter** threads into most 1¼" eyepieces | $79.50 | $99.50 |
| **48mm LUMICON UHC Filter** (1.75" aperture) fits most 2" eyepieces | $159.50 | $199.50 |
| Set of Both 1¼" **DEEP-SKY** and **UHC Filters** (Save 11%) | | $159.50 |
| **LUMICON H-BETA Line Filter** (9mm bandpass at 486nm). For the California Nebula, Horsehead Nebula, and other extremely faint nebulae. | **1¼" $89.50** | **48mm $189.50** |
| **Oxygen-III Filter** for very faint planetary and diffuse nebulae, 11nm bandpass at 496nm and 501nm 0-III lines | **1¼" $99.50,** | **48mm $199.50** |
| Telephoto lens adapter for 2" or 48mm filter. Select 46, 49, 52, 55, 58mm | | $6.95 |
| Universal adapter for 1¼" filters. Adapts the 1¼" filters to any 1¼" eyepiece | | $16.00 |
| Universal adapter for 48mm or 2" filters. Allows use of any 1¼" eyepiece | | $20.00 |

**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

## ADJUSTABLE PIGGYBACK MOUNT

The LUMICON adjustable piggyback mount is ideal for telescopes of 6-16" aperture. It permits **both** vertical and sideways adjustment for optical alignment. Also ideal to mount LUMICON 80mm SUPER-FINDER™, large telephoto lenses and small telescopes up to about 5 lbs.
**LUMICON Adjust. Piggyback Mount .. $45**
Specify telescope size: 6", 8", 10", 11", 14", 16"

## H-ALPHA PASS FILTER

Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

| Specify Lens Size | H-Alpha | (MV) |
|---|---|---|
| 46, 48, 49mm | $35.00 | $29.00 |
| 52, 55, 58, 62mm | $45.00 | $35.00 |
| 67, 72, 77mm | $52.00 | $45.00 |
| 82mm | $55.00 | |

Hypered 2415 film, 36 exp . . . **$10.95** . . . **3/$29**

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# DEEP-SKY ASTROPHOTOGRAPHY

# SR-V 3200 NEW FILM

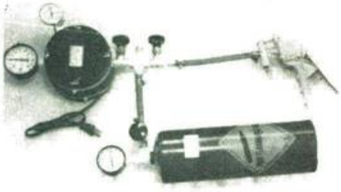
### FILM HYPERSENSITIZATION KITS†

**LUMICON HYPER-KITS™** yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

U.S. Patent 4,473,636

### MAKE YOUR OWN HYPERED FILM

**MODEL 300 HYPER-KIT** sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds ...... **$295.00**



**MODEL 600 HYPER-KIT** [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates ...... **$350.00**

**MODEL 1200 HYPER-KIT** is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller .. **$595.00**

Temperature controller for any HYPER-KIT ...... **$59.50**

Electric Vacuum Pump, Model R-10 **$280.00**

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All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X easier guide-star selection, use 48mm filters, 360° camera rotation, large prisms for bright guide-stars.
*Specify Camera and Telescope type.*
U.S. Patent #4,448,500

### NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2" or 1¼".

| | |
|---|---|
| NEWTONIAN EASY-GUIDER | **$169.50** |
| 3X Relay Diagonal (see photo) | **$79.50** |
| Illuminated reticle eyepiece system | **$89.50** |

Guider for Hasselblad **$350,** Mamiya 645 **$199**

### CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**
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Adapter for Hasselblad **$185,** Mamiya 645 **$159**

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For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**
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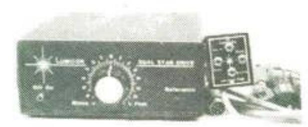
### WHAT DO YOU NEED?

1. Illuminated reticle eyepiece ...... **$89.50**
Lumicon 12mm eyepiece system has adjustable L.E.D. illumination, dual crosslines, battery pack.
2. Cable release for long exposures .. **$9.95**



3. **LUMICON Quartz Drive Corrector $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.
**Declination motor (state telescope) .. $70**
**NEW** Deluxe Digital Qtz. Drive Correc. **$298**

NEW
SRV3200

### HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

| Film Type, 35mm | Exposures | Price |
|---|---|---|
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| SRV3200, fastest of all, color neg | 24 | $13.95 |
| Konica SR1600, very fast, fine gr. | 24 | $12.95 |
| Konica SR400, fine grain color neg | 12 | $10.95 |
| 3M 1000, fastest slide film | 12 | $12.95 |
| Fujichrome RD100, fine grain slide | 24 | $12.95 |
| D-19 B&W Developer | 1 gal. | $6.95 |

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## NEW! NON-ROTATING HELICAL FOCUSER

**LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6'' telescope.**

LUMICON has just designed a deluxe smooth helical focuser with non-rotating 2'' i.d. eyepiece holder. It has a vertical travel of 1¼'' and a very low profile only 1½'' high. It is CNC machined, black anodized, and a perfect match to LUMICON EASY-GUIDERS.

**Select your desired base-plate shape!**
Flat, 7'' OD, 9½'' OD, 12½'' OD, 16'' OD, 20'' OD, SUPER-FINDER base plate.

**LUMICON Deluxe Helical Focuser** ... **$79.50**
3 handles (see photo) .............. **$12.95**
Helical focuser with 3 handles ....... **$92.40**
**2''/1¼'' adapter** w/48mm filter threads **$20.00**
**2'' LUMICON EASY-GUIDER** ....... **$169.50**

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These adapters allow high magnification photography of the Moon and Planets using eyepiece projection. They may be used without any eyepiece for prime-focus photography. All adapters use standard camera T-rings.

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1¼'' prime Focus adapter, fits 1¼'' focuser **$22**
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## LUMICON 50mm, 80mm SUPER-FINDER™

Visual Astronomers prefer the LUMICON 80mm SUPER-FINDER™, since hundreds of deep-sky objects, including most Messier objects, are visible directly. SUPER-FINDERS also make nice small portable telescopes. 80mm aperture, F=300mm coated achromat. The deluxe SUPER-FINDER uses an 80mm, F=500mm air spaced achromat.

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1¼'' right-angle version, w/star diagonal .... **$195**
2'' right-angle version, non-rotating focuser .. **$199**
1¼'' Deluxe right-angle Super-Finder* ...... **$279**
2'' Deluxe right-angle Super-Finder* ....... **$309**
25mm Cross-hair 1¼'' eyepiece (12X) ....... **$29**
*1¼'' Star Diag. **$32**, 2'' Star Diag., silver, **$145**
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These adapters convert refractors and Schmidt-Cassegrain telescopes for 2'' operation. They allow use of 2'' accessories, such as the LUMICON 2'' EASY-GUIDER for photography. They also allow use of 2'' eyepieces and/or 2'' star diagonal for viewing.

2'' adapter for C-8, Meade 2080, etc.... **$26.00**
2'' adapter for Criterion 4000, 8000 ... **$26.00**
2'' adapter for C-80, C-90, C-100 ..... **$39.50**
2'' adapter for C-70, C-80F, C-90F, C-100F **$39.50**
2'' Accessory adapter for Comet Catcher*, C-6*, Meade 310, 320 refractor ........... **$30.00**
2'' adapter for Takahashi E-130, 160 .. **$59.50**

## COMA CORRECTOR MULTIPLIER - 2'' BARLOW

These custom-designed LUMICON lenses correct aberrations in f/4 to f/5 Newtonians, and thread directly into LUMICON 2'' Easy-Guiders. The LUMICON Coma Corrector/Field Flattener improves photographic star images for fast Newtonian telescopes by correcting coma and flattening the field. Off-axis star images are much smaller, making off-axis guiding easier, and reducing the off-axis star image size in photos. The LUMICON Multiplier/Field Flattener multiplies the image scale by 1.8X (f/4.5 becomes f/8) with the included extension tube (1.5X w/o extension). The multiplier may also be used visually as a highly corrected 2'' Barlow lens. Lens designs are optimized for f/4.5 and all surfaces are multi-coated.

**48mm Coma Corrector/Field Flattener $285.00**
**1.5X/1.8X Multiplier/Field Flattener . $195.00**
**LUMICON 2'' Easy-Guider** (St. camera) **$169.50**

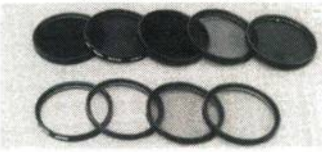
## VIEWING ADAPTERS

2''/1¼'' Adapter, threaded 48mm filters .. **$20**
2''/T - Thread adapter, threaded 48mm .. **$25**
T - Thread/1¼'' adapter. Converts telephoto lenses for viewing as finderscopes ............ **$25**

## EXTENSION TUBES

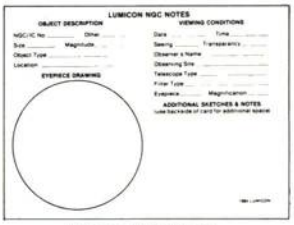
1.0'' long Thread-in extension tube **$12.00**
1-2½'' long, threaded for 1¼'' filters **$16.00**
4½'' long extension tube, 1¼'' i.d. **$25.00**
2'' i.d. Extension tube, 3'' long, threaded for 48mm filters, adds 1.6-3.0'' ....... **$26.00**

## 48mm COLORED GLASS FILTERS



These 48mm Filters thread into LUMICON EASY-GUIDERS and most 2'' eyepieces. Use adapter for 1¼'' eyepieces. AR Coated.

| Filter: | Bandpass | Trans | Price |
|---|---|---|---|
| **Ultraviolet** | 320-420nm | 85% | **$35** |
| **Minus Violet** | 420nm-IR | 96% | **$29** |
| **Blue Tricolor** | 340-470nm | 80% | **$35** |
| **Hi Perf. Blue** | 300-540nm | 95% | **$35** |
| **Yellow** | 480nm-IR | 98% | **$18** |
| **Green** | 490-590nm | 60% | **$18** |
| **Orange** | 560nm-IR | 98% | **$18** |
| **Red** | 600nm-IR | 98% | **$18** |
| **H-Alpha Pass** | 640nm-IR | 95% | **$35** |
| **Cyan** | 340-580nm | 95% | **$59** |



LUMICON NGC NOTES
OBJECT DESCRIPTION
VIEWING CONDITIONS
EYEPIECE DRAWING
ADDITIONAL SKETCHES & NOTES

## NGC NOTES

These handy **NGC NOTES** are stiff 4''X5½'' cards. the **NGC NOTES** fit in your hand and are ideal for making notes and sketches while observing at the eyepiece. Making sketches **greatly improves** your observing skills and also gives you a permanent record. Get 200 **NGC NOTES** for Messier objects; NGC object observers should get 400-800 **NGC NOTES.**

**NGC NOTES,** Pack of 200 ......... **$9.95**
Pack of 400 **$17.95** Pack of 800 **$32.95**

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New Meade MTS telescopes in stock!
6'' f/4 **$595**, 8'' f/4 **$895**, 8'' SCT **$895**, 10'' SCT **$1495**
Call for details on available options for MTS telescopes

## NEW! 2080/LX5 w/MCOG .... $1685
## MEADE 2120/LX5 w/MCOG ... $1999

The most advanced Schmidt-Cassegrain telescope available! *Standard equipment* includes dual-axis hand-held electronic command center, 2'' mirror star diagonal, 9X60mm polar viewfinder, multi-coated/enhanced optics, 26mm Super Plossl, tripod and wedge.

#39 Electric declination for 2080 or 2120/LX5 **$109**
Dew shield-essential 8'' (#712) **$65**; 10'' (#710) **$98**
Accessory shelf for field tripod ($40 list) .... **$28**
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Computer control system, 8000 object memory **$1495**

8'' LX5 $1685
10'' LX5 $1999
10'' LX3 $1799

**Meade 8'' Model 2080/LX5:** Shown with *standard-equipment* 9X60mm finder, dual-axis controller, 2'' Diagonal Mirror, Equatorial Wedge, Field Tripod.

## NEW! MTS TELESCOPES

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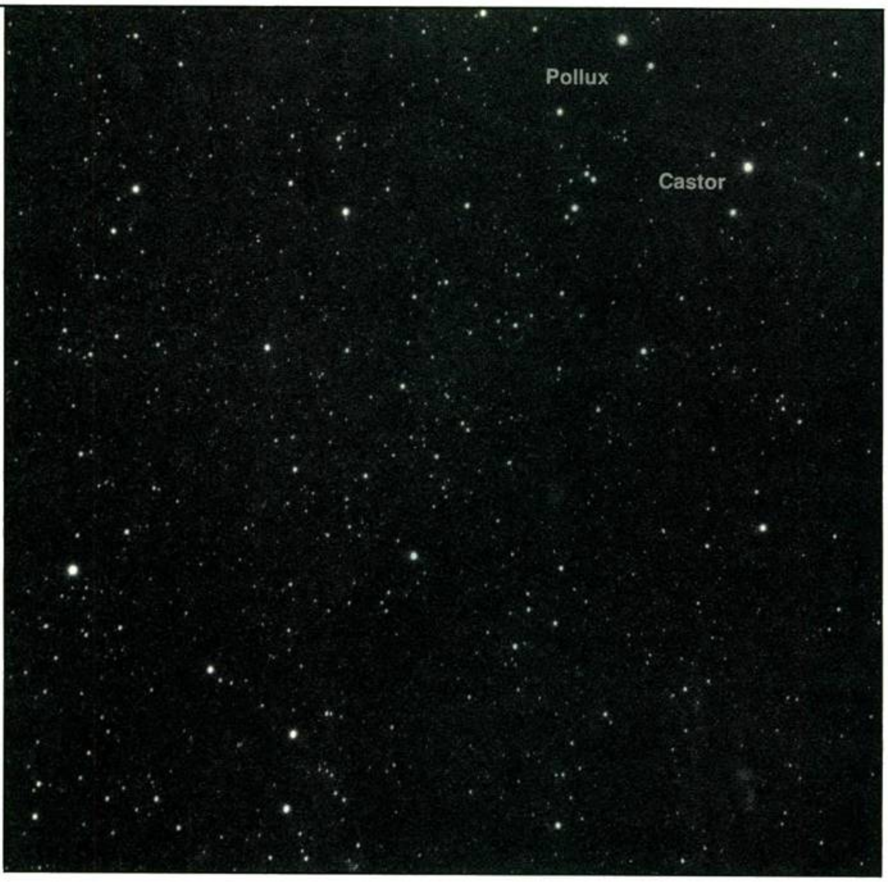
# A Meeting of Planets: Mars, Saturn, and Uranus

by Robert Burnham



## The Wanderers

As the cold shadows of late afternoon merge and darken at sunset, pinpoints of light come out in the sky's deepening blue. But the two most prominent "stars" are really planets — celestial wanderers with no fixed home in the stellar backdrop.

Aside from the Moon, the brightest object you can see is in the southwest: **Venus**, the famed "evening star." Shining brilliant white at magnitude −4.1. Venus is prominent even when partly hidden by bare tree branches. Over the month you will see it gradually gain a little elevation and stand out a little more.

As Venus climbs a bit, the other bright point of light in the southwest, **Jupiter**, drops down as if to meet Venus. (They will pass about 2° apart in early March.) Jupiter shines white at magnitude −2.2 and, together with Venus, totally dominates their dim stellar region (Pisces).

To see the rest of the planets, however, you'll have to awaken before dawn and go out — well bundled up! — when morning twilight first begins to lighten the frosty sky. In the southeast you will see several objects, among them **Mars** and **Saturn**. (See the diagram above.) At magnitude 1.3, Mars is dimmer than Saturn (magnitude 0.6) but has a distinctly warm color, while Saturn merely looks off-white. A ruddy star, Antares, is a little brighter than Mars and might be mistaken for Mars, except that Antares lies well to the right.

From night to night Mars and Saturn will appear to move toward each other, though they do not meet until February 23, when Mars passes about three Moon-diameters south of Saturn. A carefully matched series of photos taken at the same time of day for a week centered on the 23rd will show this stately ballet at its best. Use a medium telephoto lens, fast film, a tripod, and exposures running 1, 2, and 5 seconds.

One day before it meets Saturn, Mars passes only 40″ north of **Uranus**, a dim planet on the edge of naked-eye visibility. A small telescope at least is needed to reveal Uranus' disk, but any pair of binoculars easily shows the planet as a stellar dot of light at magnitude 5.7. Saturn also passes north of Uranus (on February 12), but the distance between them is about the same as when Mars and Saturn meet. Of the two Uranus conjunctions, therefore, the one with Mars is closer and more dramatic and will point out Uranus better.

In the last ten days of February **Mercury** pops into view low in the southeast. Although it won't climb higher than 4° (forty-five minutes before sunrise), Mercury will be visible for about a month. Highest elevation comes at the end of February, though Mercury's greatest separation (elongation) from the Sun is on March 8. At magnitude 0.4 on February 29, Mercury is as bright as Saturn but redder.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

## The Starry Sky

When the last traces of twilight vanish from the western sky, winter's constellations will parade across the evening heavens. Crossing the meridian in the south is blazing Sirius, the chief luminary of **Canis Major** the Greater Dog and the sky's brightest star. Forming a stick figure below Sirius are the Dog's body and hind legs, while the Dog's forepaws extend to the west.

Above and to the right of Sirius strides the great Hunter **Orion**, his shoulder and knee marked by ruddy Betelgeuse and icy Rigel, respectively. Below his three-starred belt hangs a sword with its nebula-jewel M42. Orion's arm, depicted in the faint Pi (π) stars, holds a shield against **Taurus** the Bull. The Bull's head is made from the "V" of the Hyades cluster stars plus interloper Aldebaran; the Pleiades sit on his shoulders.

Taurus is part of the zodiac, twelve constellations that line the ecliptic, the path taken by the Sun. Westward from Taurus the ecliptic is dull, but one figure near Taurus is of interest tonight: **Cetus** the Whale, diving over the western horizon. In Cetus' tail is Mira, a famous variable star that last month shone its brightest in nearly a year. See if you can see its magnitude change during February.

Taurus' horns point east, one toward

**Top: The constellation Gemini. Photo by Stephen Walther.**

**Opposite page: The Full Moon and Jupiter (just below the Moon) above a snowy Canadian trailer park. Photo by Brian McNair, taken on Ektachrome 400 film with a 20-second exposure.**

# February Night Sky

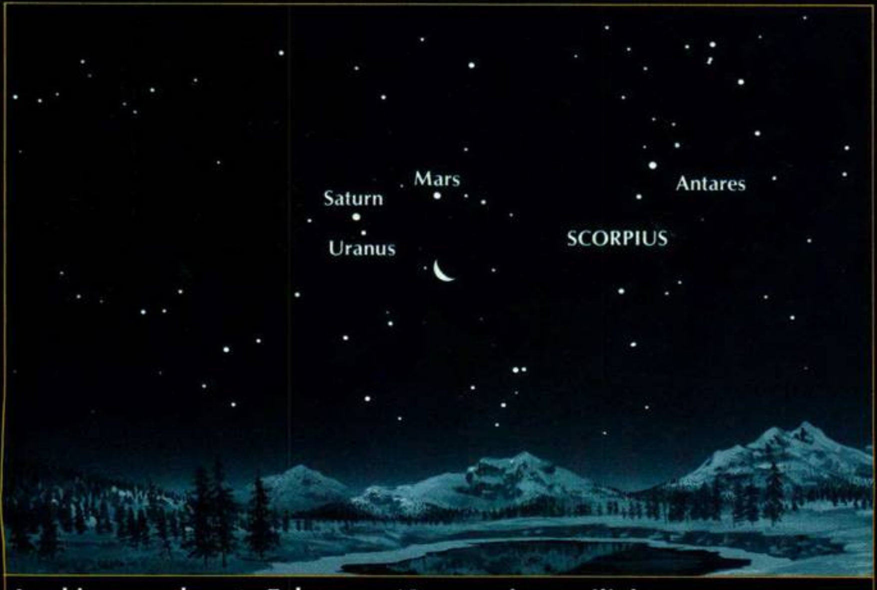
Full Moon
February 2
3:51 p.m. EST

Last Quarter
February 10
6:01 p.m. EST

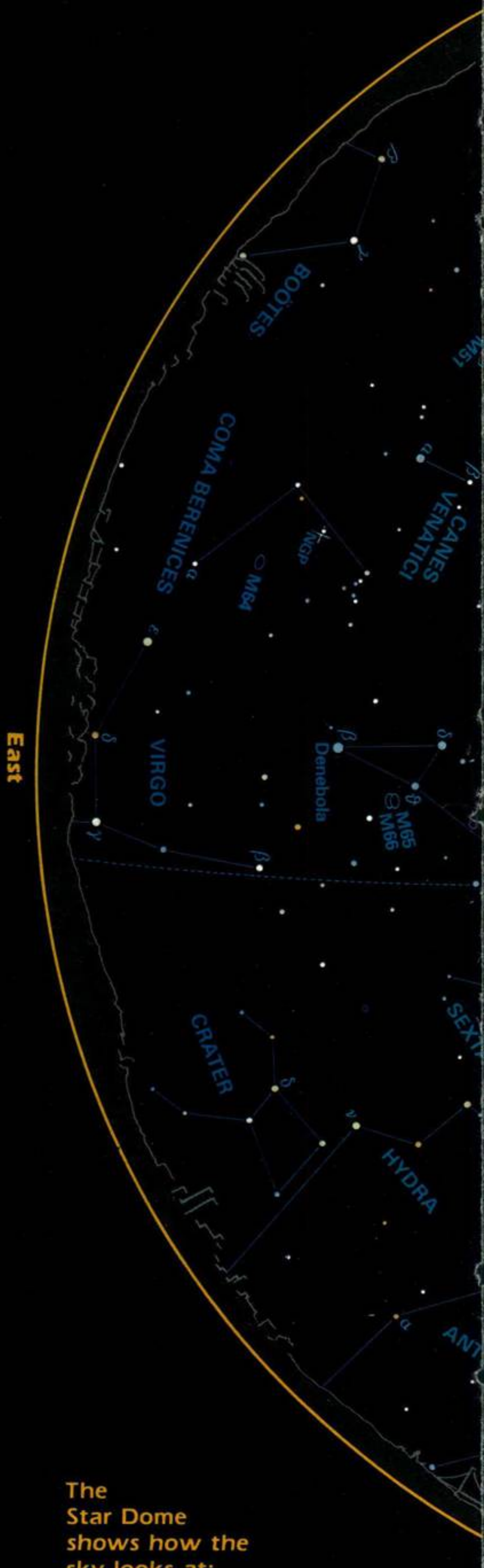
New Moon
February 17
10:54 a.m. EST

First Quarter
February 24
7:15 a.m. EST

| | |
|---|---|
| **2nd** | Full Moon occurs at 3:51 p.m. EST. |
| **3rd** | The Moon is farthest from Earth at 5:29 a.m. EST: 252,522 miles (406,395 kilometers). |
| **8th** | The Moon passes south of the star Spica in the late evening, covering the star for viewers in Indonesia, Antarctica, parts of Australia, and far southern New Zealand. |
| **10th** | Last Quarter Moon is at 6:01 p.m. EST. Late tonight Mercury passes between the Earth and Sun. It becomes visible in about a week, low in the southeast before sunrise. |
| **12th** | In the morning sky the Moon passes south of the star Antares, covering Antares for viewers in southern South America and Antarctica. Tonight Saturn passes 1.3° north of Uranus but is below the horizon at the time of closest approach (see text). |
| **13th** | The Moon lies near Mars, Saturn, and Uranus in the morning sky (see diagram below). |
| **17th** | The Moon is closest to Earth at 4:43 a.m. EST: 221,776 miles (356,914 kilometers). New Moon is at 10:54 a.m. EST. |
| **20th** | Tonight the Moon lies between Venus and Jupiter. |
| **22nd** | Mars lies 40″ north of Uranus (see text). |
| **23rd** | Mars passes 1.3° south of Saturn in the morning sky. |
| **24th** | First Quarter Moon occurs at 7:15 a.m. EST. |

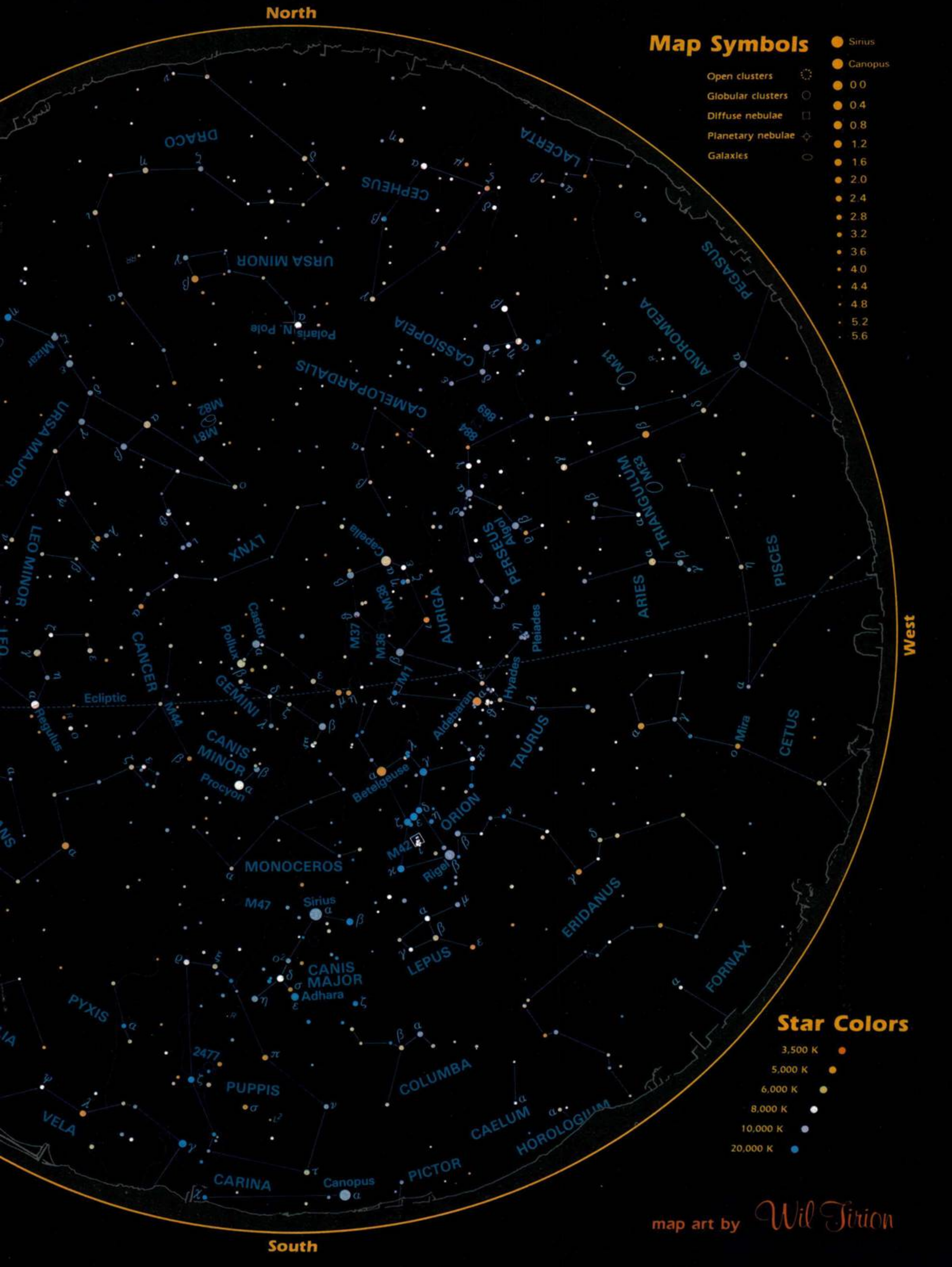


Looking southeast, February 13, morning twilight

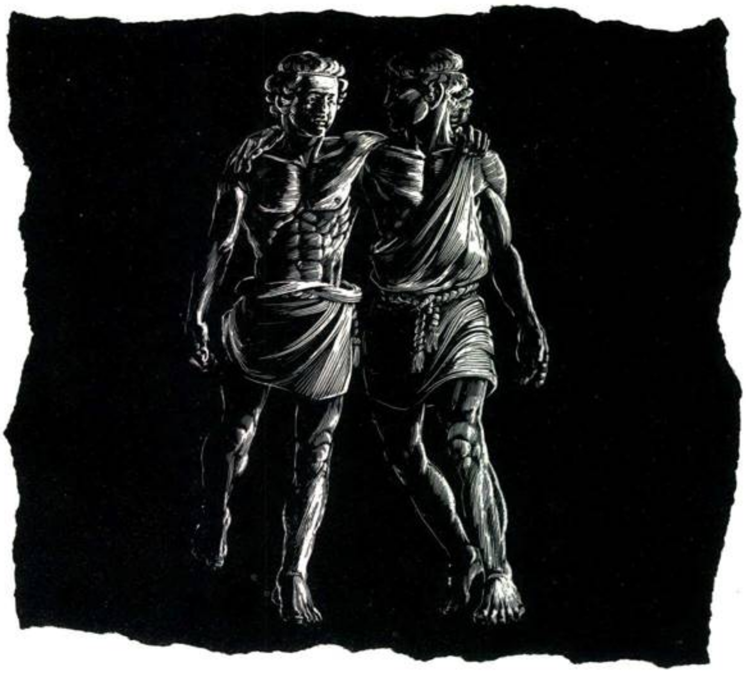


The
Star Dome
shows how the
sky looks at:

10 p.m. on February 1
9 p.m. on February 15
8 p.m. on February 29


North
South
West
Map Symbols
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
DRACO
CEPHEUS
LACERTA
URSA MINOR
Polaris N. Pole
CASSIOPEIA
PEGASUS
ANDROMEDA
M31
CAMELOPARDALIS
Mizar
URSA MAJOR
M81
M82
869
884
M33
TRIANGULUM
PERSEUS
Algol
LYNX
LEO MINOR
Capella
AURIGA
M38
M37
M36
ARIES
PISCES
Pleiades
Castor
Pollux
CANCER
GEMINI
M1
Hyades
Aldebaran
TAURUS
Ecliptic
Regulus
M44
CANIS MINOR
Procyon
Betelgeuse
ORION
Mira
CETUS
MONOCEROS
M42
Rigel
M47
Sirius
ERIDANUS
LEPUS
CANIS MAJOR
Adhara
FORNAX
PYXIS
2477
PUPPIS
COLUMBA
VELA
CAELUM
HOROLOGIUM
PICTOR
CARINA
Canopus

map art by Wil Tirion



Keith Ward

**Auriga** the Charioteer, the other toward zodiacal **Gemini** the Twins (see Skylore). Gemini forms a long rectangle with Twins Castor and Pollux at one end; the brothers stand with their feet in the Milky Way. Below Pollux solitary Procyon lends its light to faint **Canis Minor** the Lesser Dog. Auriga's large pentagon is easy to trace once you locate 1st-magnitude Capella's yellow hue, while inside the pentagon lie a couple of Milky Way star clusters.

From Auriga the Milky Way flows in a steadily dimming stream down toward the northwest horizon. On its path it passes **Perseus** the Rescuer and **Cassiopeia** the Queen. Perseus isn't very distinct, but its stars are the brightest that lie between Auriga and the crooked "W" of Cassiopeia. The Queen perches on her uncomfortable throne, circling Polaris roughly opposite the **Big Dipper**, now rising in the northeast.

When you face due east, the Lion **Leo** is springing toward Gemini with only faint **Cancer** the Crab intervening. Both Leo and Cancer are members of the zodiac. Leo is depicted in a crouch; Leo's forepaws are found at Regulus (the "little king"), while its tail lies at Denebola, low on the horizon. Leo's head and shoulders make a backward "?" often called the Sickle.

Let's now venture into the dark stellar ground below Canis Major. (You may need to get out of the city for dark skies and an unobstructed southern view.) At the Dog's feet stands the stern of Jason's ship *Argo*. Called **Puppis**, this figure is *Argo*'s most prominent part. East of Puppis a dim, anachronistic Compass (**Pyxis**) keeps the Argonauts on course, while the Sails (**Vela**) and Keel (**Carina**) lie farther below with only their northernmost parts drifting into view for us.

But if you live south of latitude 35°, look straight down from Sirius for a silver-white star lying very low. This is Canopus, the brightest nail in the Ship's Keel and a splendid symbol of all stellar riches lying beyond the horizon.

## Skylore

The bright pair of Castor and Pollux has fascinated skywatchers for thousands of years. In the skylore of every civilization open to us these two stars, only 4-1/2° apart, have played prominent roles. Although the constellation name Gemini is Roman, even the Sumerians of 4000 B.C. envisioned a pair of brotherly twins in these two stars.

The Egyptians saw them as Horus rising and Horus setting — a complementarity also found among the Chinese, for whom the two stars embodied the yin-yang duality of nature. Among the Hindu the pair was the Ashwins, two beautiful youths (one fair, the other swarthy) who were godlike horsemen riding on the rays of the Sun at dawn.

The Greeks called the pair the Dioscouri, the "sons of god," and said the two stars were the offspring of Zeus and the fair Leda, wife of King Tyndareus. Zeus had ravished Leda when he was disguised as a swan. In return she gave birth to two eggs, one hatching Castor and Clytemnestra, the other Pollux and Helen.

Castor and Clytemnestra were mortals because they shared a half-mortal parentage, while Pollux and Helen were immortal. But the two brothers, so identical no one could tell them apart, were raised together and remained inseparable. Olympic athletes both, Castor gained fame as a charioteer and breaker of horses while Pollux excelled at the art of boxing.

Following the call of adventure, they joined Jason's expedition into the Black Sea in search of the Golden Fleece. On the way to Colchis, as Apollonius of Rhodes tells it, the *Argo* stopped on the north coast of Asia Minor in the land of the Bebryces. King Amycus, a giant bear of a man, was notorious for not letting visitors pass through his realm without challenging them to a boxing match — a challenge no stranger was allowed to decline and which none had survived.

Pollux was the first Argonaut to step forward. He donned the "gloves" — sharp-edged strips of sun-dried leather — and squared off to meet the bully. Back and forth they went until Amycus, seeking a fast end, rushed in and momentarily left his guard open. Pollux, alert despite the ferocious pummeling, saw his chance and drove his fist into Amycus' temple, breaking the skull and killing the man.

Months later on the return voyage a storm arose that threatened to sink the *Argo*. At the storm's height with spray flying and the wind screaming in the rigging, Orpheus broke out his lyre and calmed the sea with beautiful songs. Yet, strange to say, when the waves had subsided and the ship, creaking comfortably again, was plowing through the water, two bright lights shone in the heavens over the heads of Castor and Pollux.

Orpheus' thoughts on this weren't recorded but, misattributed or not, down through antiquity ships routinely carried images of Castor and Pollux on their bows to ward off shipwreck. And when the light of St. Elmo's fire started to play around the mastheads, sailors took it for a divine visitation. Even today's mild oath, "By Jiminy!", recalls a more ancient time when such a plea, made in complete seriousness, might be all that stood between you and frightful disaster.

Sadly, however, the brothers came to a grim end in later years. A cattle raid with two other ex-Argonauts went sour when the spoils were divided, and Castor was killed in a quarrel born of arrogance and a prickly sense of pride. Zeus immediately offered to let Pollux claim his immortality, but Pollux refused because Castor could not share in it. The god then offered a choice: if Pollux would endure Castor's lot in Hades for half the time, Castor could enjoy immortality the other half. Pollux accepted and eventually Zeus raised them both into the sky for their loyalty.

**Opposite page, top: The crescent Moon sets over Chicago. Photo by David Rights.**

**Opposite page, bottom: Taurus and the waning crescent Moon composed in an opening known as the "slot" in Anza-Borrego Desert State Park, California. The fissure walls are illuminated with a broad-beam flashlight. Photo by Jerry Schad, who used a 35mm lens at f/2, Fujichrome 400 film, and a 40-second exposure.**

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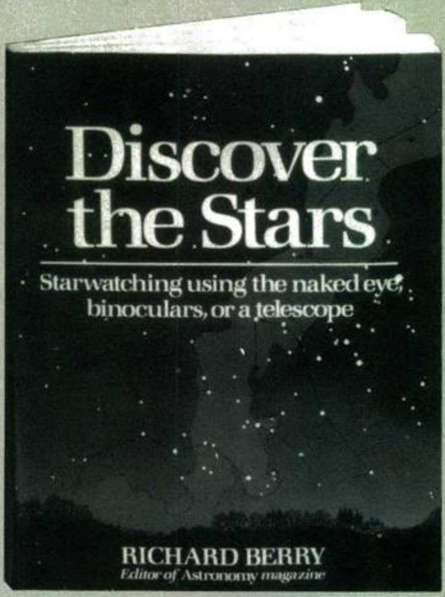
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Starwatching using the naked eye, binoculars, or a telescope
RICHARD BERRY
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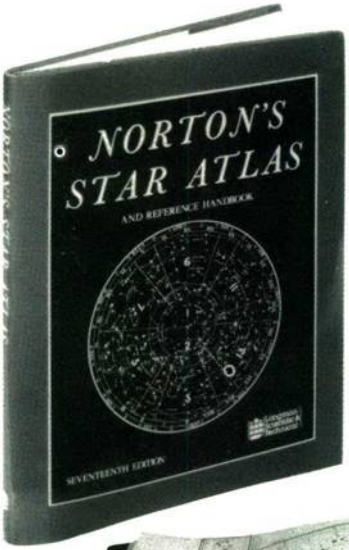

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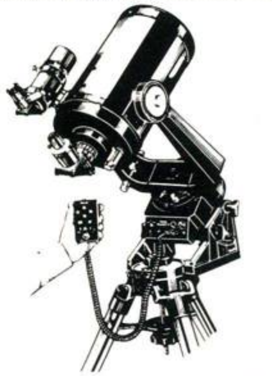

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| | |
|---|---|
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Gazer's
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# Looking for Lunar Fractures

### by Michael T. Kitt

An observer studying the lunar surface through a telescope might conclude that not only is the Moon devoid of life, but it is geologically dead as well. After all, except for the more recent ray craters like Copernicus and Tycho, the Moon's surface has remained virtually unchanged for over 3 billion years. The only change apparent on the Moon today is the monthly shadow play between slope-sided craters, craggy mountain ranges, and expansive lava plains.

And yet, careful scrutiny of the regions among the craters, mountains, and plains with even a 2-inch-diameter telescope will show features that tell the story of a younger, more dynamic Moon, its surface fractured by internal forces — volcanic and tectonic — not merely hammered into shape by meteors. Perhaps the clearest evidence for such internal forces comes in the form of narrow clefts on the Moon known as rilles.

Lunar rilles were first noticed by the Dutch astronomer Christiaan Huygens not long after the invention of the telescope. But over a century was to pass before the first serious study of these features was carried out by Johann Schroeter, the German selenographer. In 1792 he discovered the Ariadaeus cleft, a prominent rille over one hundred miles long located near the center of the lunar disk. He later charted many other clefts in detail. In recognition of this work a magnificent rille, one of the showcases of the Moon, was named "Schroeter's Valley" in his honor.

Today over two thousand lunar rilles are known from Earth-based observations and many thousands more were revealed by the Lunar Orbiter and *Apollo* mission photography. Of these, at least two hundred clefts can be observed with typical backyard equipment. Even a 2.4-inch refractor reveals nearly a dozen rilles under proper seeing conditions. Just what are we looking at when we observe a lunar cleft?

## Stress Cracks and Lava Rivers

There are three types of rilles. Straight rilles form as a consequence of the Moon's internal faulting, although in some cases these faults appear to be the result of the great basin-forming impacts that shattered the lunar crust 4.2 billion years ago. Other fractures apparently occurred as the eroded crust established an equilibrium with the basaltic layers below. Simple faults result in relatively straight clefts with V- or U-shaped profiles. Frequently two closely spaced parallel faults permit the terrain in between to drop down. This results in a wide, flat-floored cleft called a graben.

Arcuate rilles curve in gentle arcs and are most often found near the edges of the lunar maria. These rilles formed as the dense basalts of the maria sank into the crust under their own weight, which causes stress cracks to appear along the perimeter of the basin. Often two or more parallel arcuate rilles formed, creating a steplike arrangement termed *en echelon* (French for "rung of a ladder"). Because of the numerous concentric faults that occurred as the mare regions sank, the arcuate type of rille is more predominant than the graben form.

The third kind of cleft is the sinuous rille, a winding structure reminiscent of a riverbed. Sinuous rilles result from lava that once flowed through these channels. One of the major characteristics of a sinuous rille is a craterlike formation at one end, which probably served as the source of the lava flow. These craters favor the high ground with the rille snaking its way gradually toward lower elevations. The only rille explored by astronauts was Hadley Rille, a sinuous formation located at the base of the Apennine Mountains. (This was on the *Apollo 15* mission.)

Rilles also form within craters because of tectonic adjustments to crater floors. Unfortunately, most of these crater floor-cleft systems, although fascinating, are extremely delicate and therefore invisible to Earth-bound observers. Nonetheless, about twenty craters contain rilles that can be examined through backyard scopes. Many rilles are concentrated around the edges of the lunar maria, and they are quite rare in the lunar highlands or near the center of the maria.

## Observing Techniques

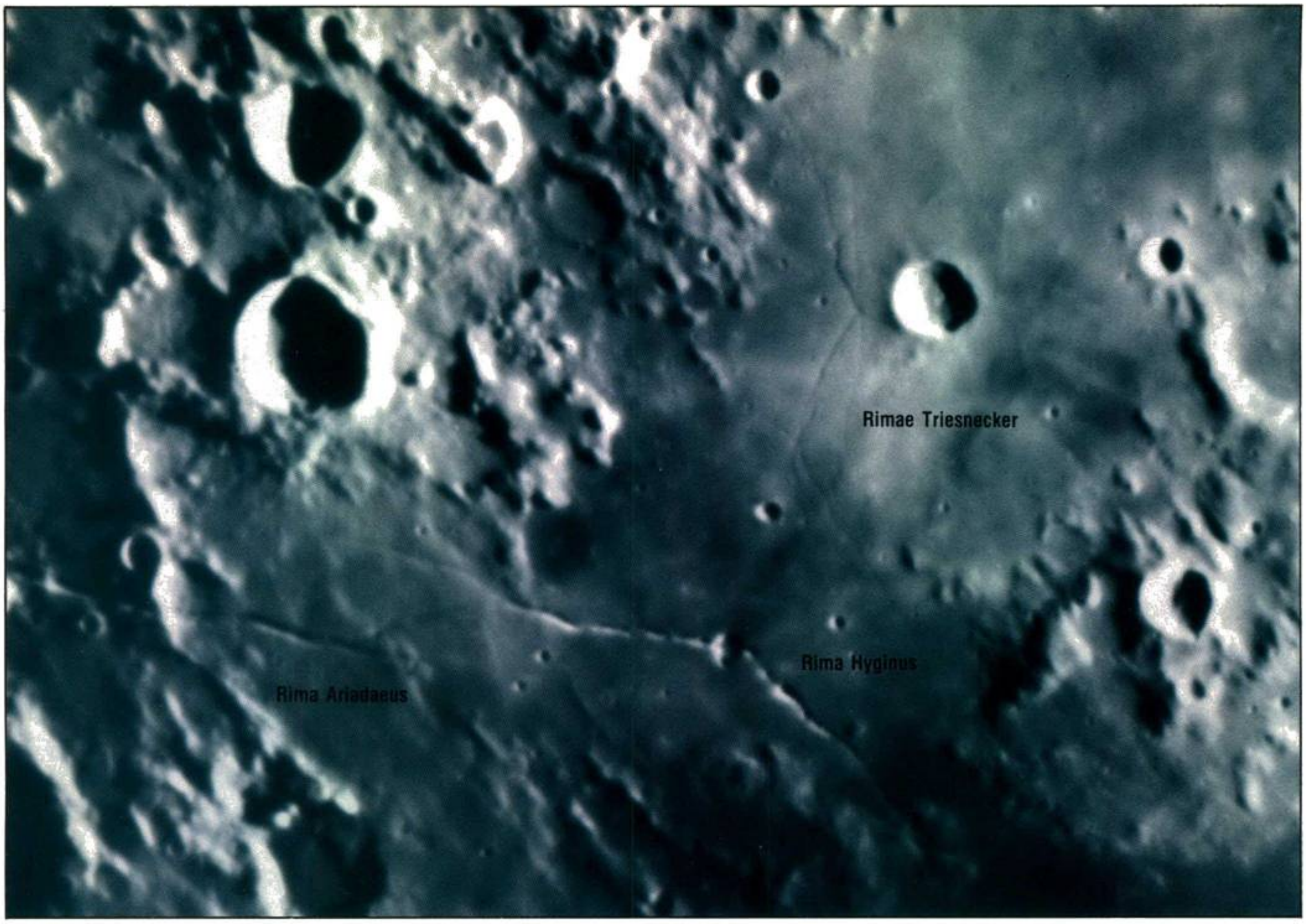
Finding rilles is similar in some respects to deep-sky observing: success depends on seeing conditions, knowing exactly where to look for the elusive object, and developing a well-trained eye. It is important to pick a time when seeing conditions are good. Rilles are impossible to observe on nights when the atmosphere is agitated by the mixing of warm and cool layers of air, no matter how crystal clear the atmosphere is. In fact, a slight amount of haze — as evident during a heat inversion — is not a detriment but often presages superb conditions for lunar observation because the air temperature at different altitudes is fairly stable.

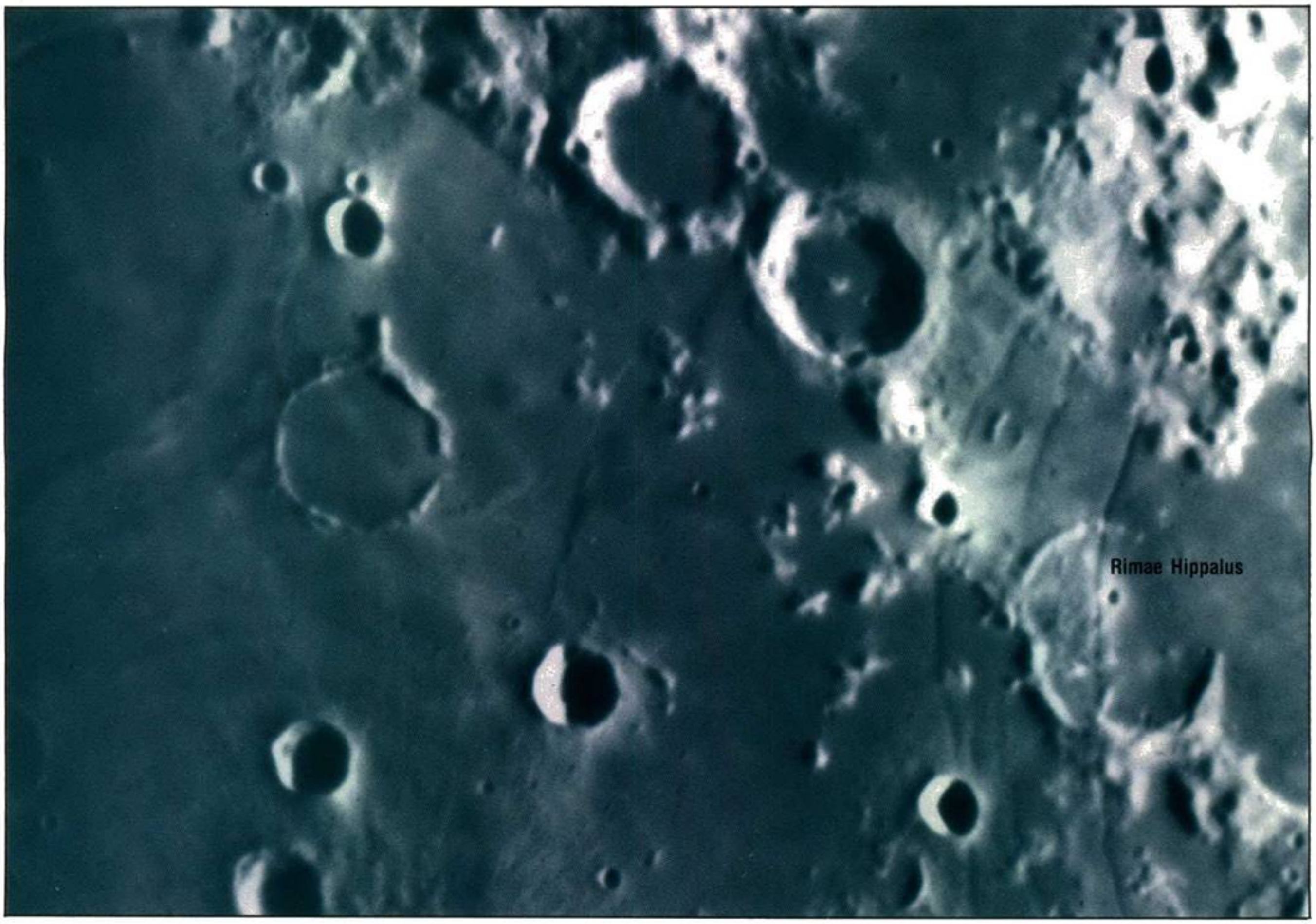
Essential to locating rilles is a good lunar map, one that not only helps you locate the rille but also pinpoints landmarks along the route of the cleft. The map found in Anton Rukl's *Moon, Mars, and Venus* is excellent (though the book is, unfortunately, out of print). Lunar maps can be found in almost every fundamental work on amateur astronomy. However, some of them concentrate on large-scale lunar features and thus are not suited to helping you locate rilles. On the other hand, maps that are so covered with labels you can't clearly see the rilles or adjacent features are also undesirable. The ideal map is comprehensive and clearly labeled.

Optimal seeing conditions and accurate lunar maps mean nothing, however, unless you work to train your eye to detect these slender linear features. This can take a little time, so go easy on yourself. I remember when I first tried to observe the Triesnecker rille system, a fine collection

**Opposite page, top: Rima Ariadaeus, Rima Hyginus, and Rimae Triesnecker are located at the center of the Moon's disk.**

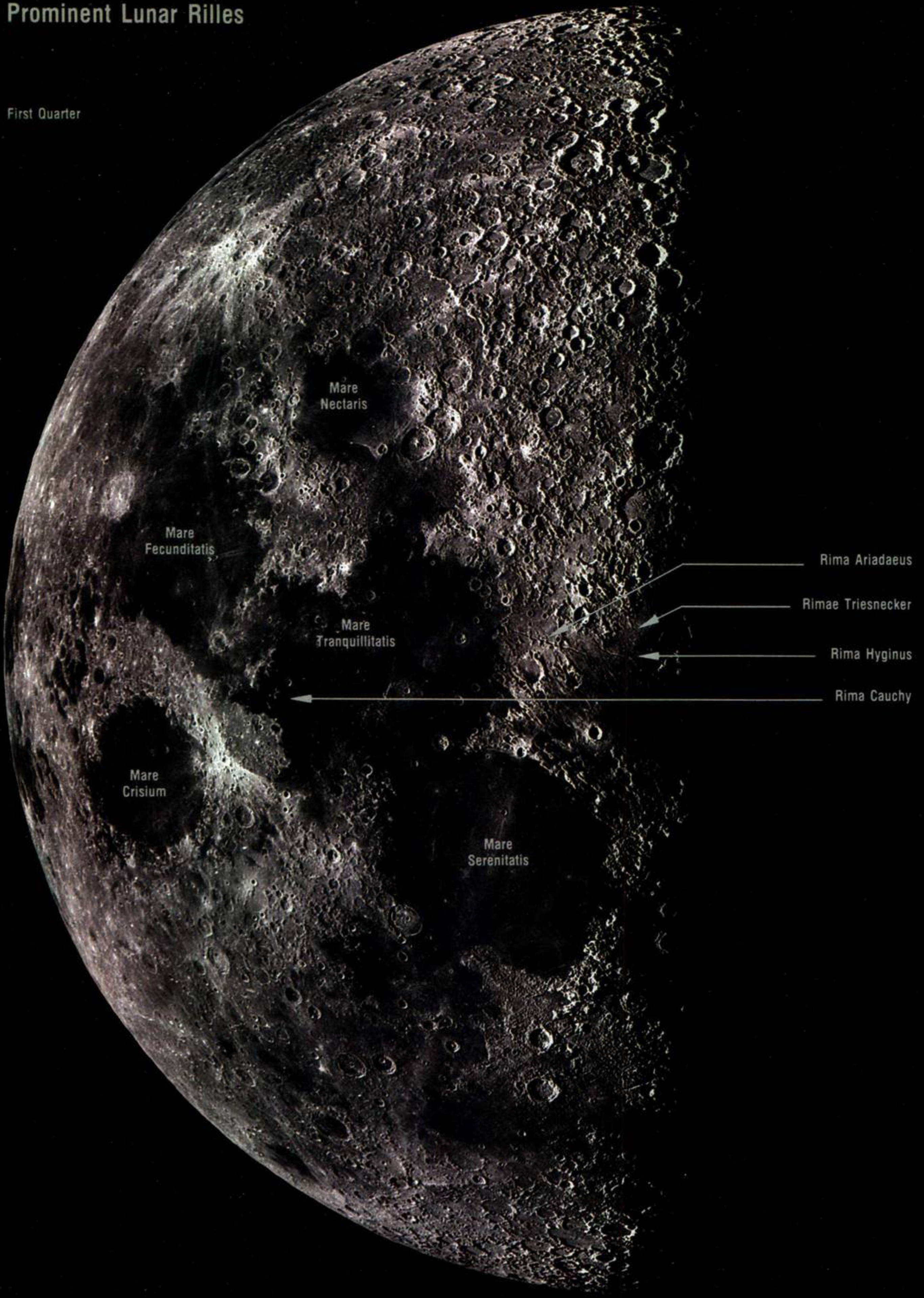
**Opposite page, bottom: The Hippalus rilles during the Moon's waning crescent phase. Photos by C. Arsidi, who used a 12-inch Cassegrain and 2415 film. South is at top in all illustrations.**

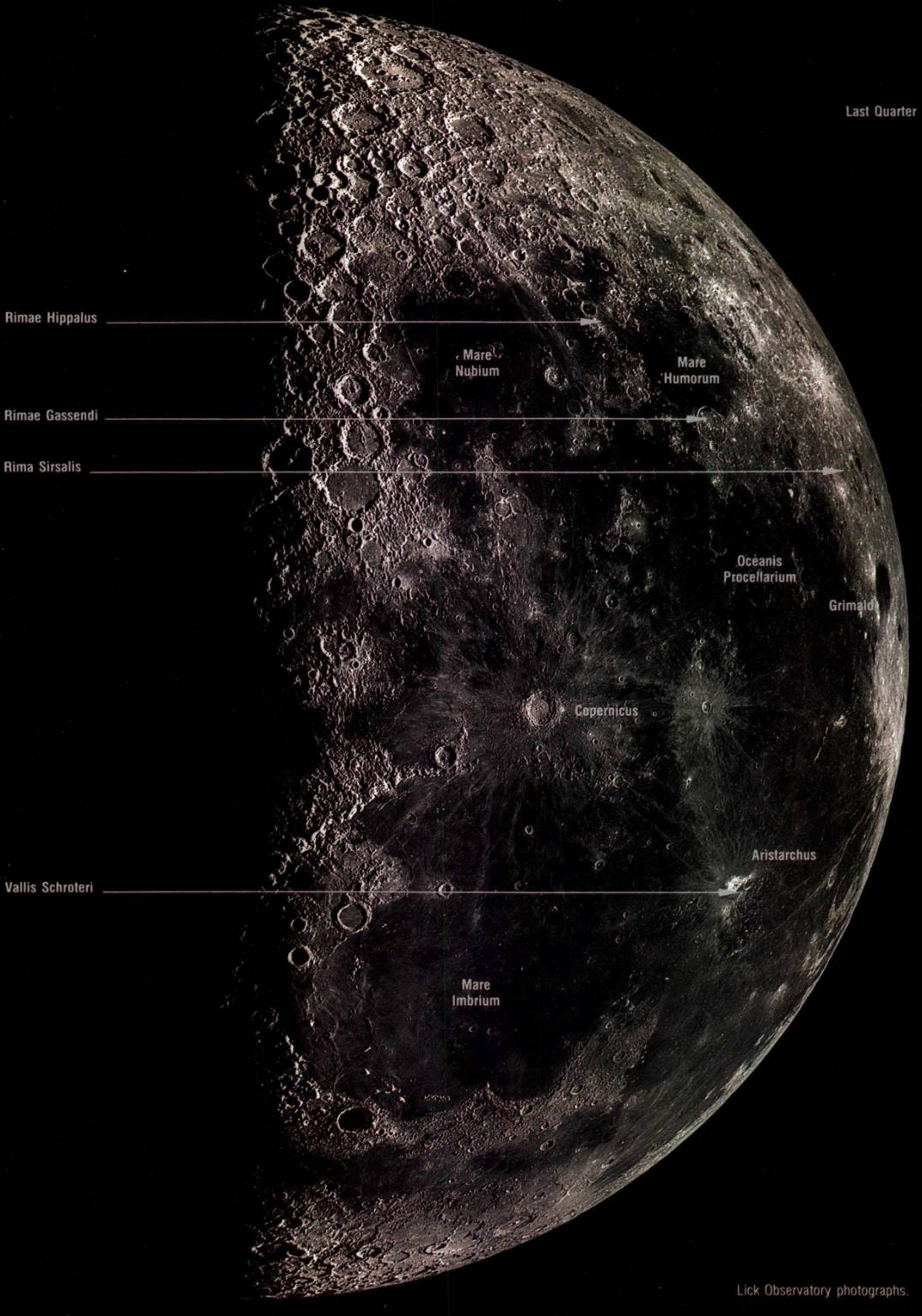

Rimae Triesnecker
Rima Hyginus
Rima Ariadaeus


Rimae Hippalus

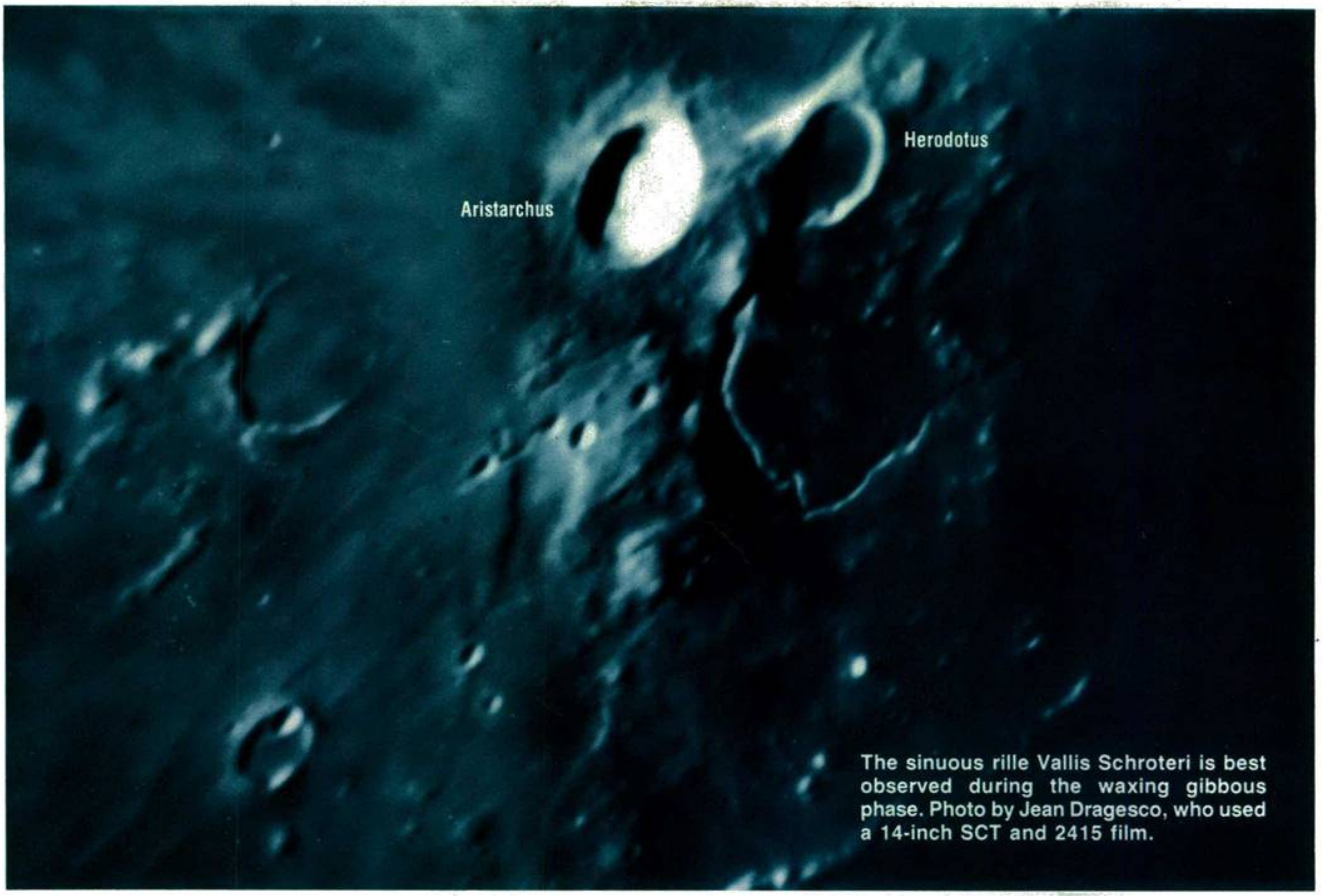
# Prominent Lunar Rilles

First Quarter


Mare Nectaris
Mare Fecunditatis
Mare Tranquillitatis
Mare Crisium
Mare Serenitatis
Rima Ariadaeus
Rimae Triesnecker
Rima Hyginus
Rima Cauchy


Last Quarter
Rimae Hippalus
Mare Nubium
Mare Humorum
Rimae Gassendi
Rima Sirsalis
Oceanis Procellarium
Grimaldi
Copernicus
Aristarchus
Vallis Schroteri
Mare Imbrium

Lick Observatory photographs.



The sinuous rille Vallis Schroteri is best observed during the waxing gibbous phase. Photo by Jean Dragesco, who used a 14-inch SCT and 2415 film.

of clefts near the center of the lunar disk. Many months passed without success: the seeing never seemed quite good enough. Then one month at the appropriate time for observing this feature, viewing conditions were nearly perfect and it all clicked into place. There, looking for all the world like a fine spider web in my scope, was the magnificent group of clefts. To my surprise I found that during succeeding lunations the Triesnecker rilles were relatively easy to locate and that I could observe them under a wide range of seeing and lighting conditions. They had been observable during all those fruitless months of searching, but I just hadn't realized what I was looking for.

This effect is encountered in all phases of observational astronomy: the *trained* eye always sees more. Once you observe a particular rille the first time, you'll detect it quicker and note increasingly more detail during subsequent viewing sessions. The trick is to persevere until you do see it for the first time. It may take excellent seeing conditions to achieve that first glimpse, but afterwards I guarantee you won't be able to understand how you missed the rille before.

All but the very largest rilles are less than one-and-a-half miles wide. A quick calculation confirms that a crater only one-and-a-half miles in diameter cannot be resolved by a 6-inch telescope. What makes these extremely thin clefts readily visible is their great length combined with the strong brightness contrasts they can display with respect to the surrounding terrain. When the local Sun elevation is low, one interior wall of a rille will be in complete shadow. Meanwhile the opposite wall will appear brightly lit because it faces the Sun more directly than the surrounding terrain. Under these conditions a rille presents itself as a fine, sharply defined line.

The most important factor in locating and observing rilles is lighting. If the Sun's angle is not right, the rille is undetectable. Generally, the best time to observe rilles is when the feature displays the greatest contrast. This usually occurs about one day after sunrise or before sunset over the lunar feature of interest; that is, when the terminator (the boundary between the dark and sunlit hemispheres) is about 6 to 12 degrees in longitude away from the rille. Most clefts are impossible to detect in any instrument three or four days after sunrise over the feature. Rilles running parallel to the terminator, however, are easier to detect than those that trend east to west because the parallel rilles display greater contrast.

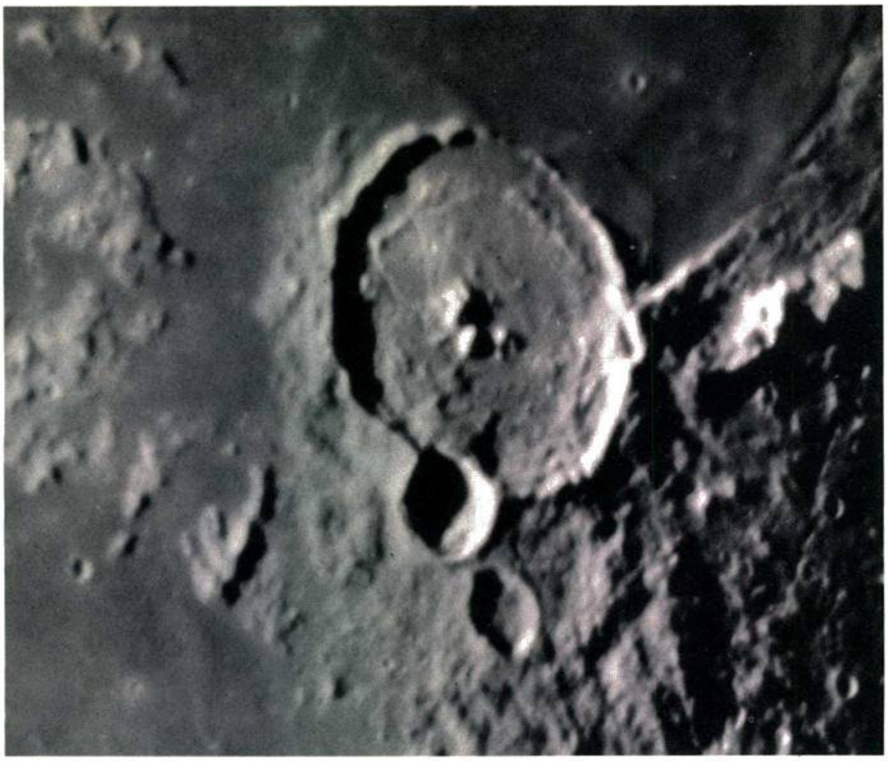
### A Lunar Rille Sampling

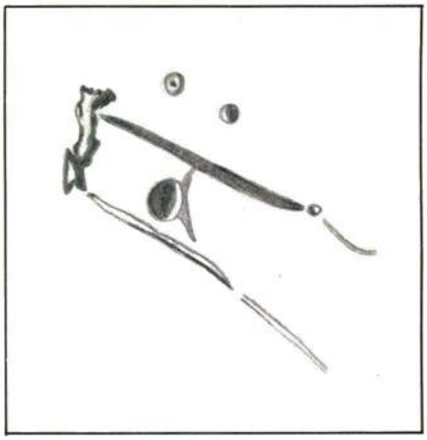
Out of the two hundred observable lunar rilles, I've selected the most interesting rilles that can be easily detected in a small telescope. They are listed in the order in which they make their appearance each lunar month — from waxing to waning phases.

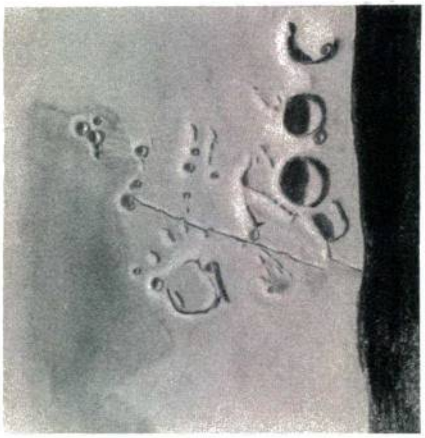
*Rima Cauchy*. This straight rille, over 150 miles long, is one of my favorites because of the unusual variety of features in its vicinity. Rima Cauchy is located in the northeast sector of the Mare Tranquillitatis, just to the north of Crater Cauchy. Running parallel to the rille and south of this crater is a striking fault, similar to the famous Straight Wall in Mare Nubium. This fault is transformed into a rille for the southeast one third of its length. Complementing this beautiful arrangement are two fine lunar domes, Cauchy Omega and Tau, a little farther to the south. Observe this rille when the Moon is still in the crescent phase; by First Quarter the rille is undetectable.

*Rima Ariadaeus*. A spectacular straight graben, Rima Ariadaeus is very wide and favorably placed near the center of the Moon's disk. It runs northeast to southwest through highland terrain and seems to connect Mare Tranquillitatis with Sinus Medii. The walls of this cleft are very pronounced a day or two before First Quarter. Larger telescopes reveal that this cleft is offset by its own width at one point, which is suggestive of strike-slip faulting, where one segment of a fault slips horizontally out of line with another segment.

*Rima Hyginus*. The Hyginus cleft is yet another straight rille, and it is most likely geologically related to the Ariadaeus rille. It lies to the northeast corner of Sinus Medii, where it runs parallel to Rima Ariadaeus until it reaches the crater Hyginus. There it abruptly veers some 30 degrees to the northwest and trends toward Mare Vaporum. This northwest arm boasts one







**The rilles crossing the floor of Crater Gassendi, visible in this photograph by Jean Dragesco, are a good test for the eye. Easier rilles are Rima Cauchy (top sketch), drawn four days after New Moon with an 8-inch SCT at 155x, and Rima Ariadaeus (bottom sketch), as it appears two days before First Quarter at 266x in an 8-inch Newtonian. Sketches by Michael Kitt and Jeff Kanipe, respectively.**

of the best examples of a crater chain within a cleft.

Rima Hyginus is one of the very few examples of a cleft visible under all conditions of lighting: at First Quarter phase the rille is a gull-shaped line with considerable contrast; Crater Hyginus is dark with a bright west rim. At Full Moon the cleft is an obvious bright line southeast of Mare Vaporum.

*Rimae Triesnecker*. The Triesnecker clefts are a beautiful complex of seven crisscrossing straight rilles. These rilles are the most difficult objects listed here; however, their visibility is enhanced by their location at almost the exact center of the lunar disk in Sinus Medii. Look just after the First Quarter phase south of Rima Hyginus for faint lines running north to south. To see details in this unique rille system requires a large telescope.

*Rimae Hippalus*. The Mare Humorum area is home to the largest collection of rilles on the Moon. Clefts abound in all directions around the perimeter of this lunar basin. The most spectacular of these are three large, arcuate grabens arranged in gentle parallel curves along the southeast boundary of the Mare Humorum. These clefts run across highland terrain and through mare flood plains in sweeping arcs that extend over 150 miles. At least three more parallel grabens can be observed as part of this system with large telescopes. The best time to see these rilles is during the early stages of the waxing gibbous Moon and after Last Quarter.

*Rimae Gassendi*. The floor of Crater Gassendi on the northwest edge of Mare Humorum contains an impressive collection of rilles. Seven intersecting clefts can be observed, although not all of these are easy objects. The Gassendi rilles are an excellent test for the eye. Two or three rilles are the most you are likely to see at first, but you should see more detail during each additional round of observations. I have found that the illumination angle is particularly critical in detecting these rilles. The best time to look for them is three or four days before Full Moon or two or three days after Last Quarter Moon.

*Vallis Schroteri*. This magnificent sinuous rille, located near the crater Aristarchus, is one of the premier objects on the Moon. Like the Hyginus rille, it is bright and unmistakable under high illumination, but the greatest detail is revealed the first day after local sunrise. (The Moon is poorly placed in the sky during sunset on this formation.) Space-probe photography revealed an extremely sinuous rille within Schroeter's Valley, but this is not visible in telescopes. The main rille originates in a bulbous-shaped volcanic structure aptly named the "Cobra Head." Schroeter's Valley is by far the largest sinuous rille on the Moon. Most other sinuous clefts are barely visible even in moderate-sized telescopes.

*Rima Sirsalis*. We end our showcase of lunar rilles with a fine example located in the highlands southwest of Oceanus Procellarum. The Sirsalis rille is a straight north-south graben that averages 2 miles wide and 270 miles long and is located just east of Crater Sirsalis. Rima Sirsalis is best observed a day before Full Moon or during the waning crescent phase, four or five days before New Moon. Were it more centrally located, the Sirsalis rille would surely be one of the most unforgettable features on the Moon. As it is, this rille is impressive, crossing a variety of craters and hilly terrain unimpeded. Like the Ariadaeus rille, it shows evidence of slip faulting, because it is offset by its own width in one location.

For me, searching the lunar surface for these elusive cracks is a stimulating challenge not unlike deep-sky observing. While searching for rilles is a great way to learn your way around the Moon, it also gives you food for thought. The more you explore these clefts, the more you feel you're observing something that holds important clues to how and why the Moon evolved to its present state. Two hundred and twenty-two lunar formations are officially designated "rimae." Although I haven't managed to see all of them yet, I'm confident that one day I'll finish my version of the lunar "Messier Catalog."

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*Michael T. Kitt is a member of the Association of Lunar and Planetary Observers. When not observing the Moon, he enjoys deep-sky observing with the Rockland Astronomy Club in New York. His most recent article, "Sculpting the Moon," appeared in the February 1987 issue.*

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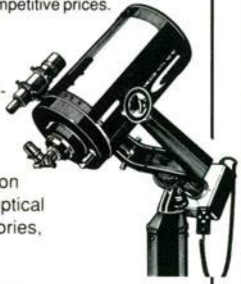

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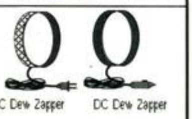

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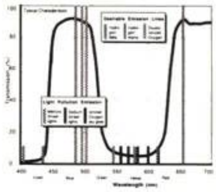

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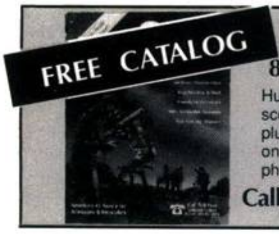

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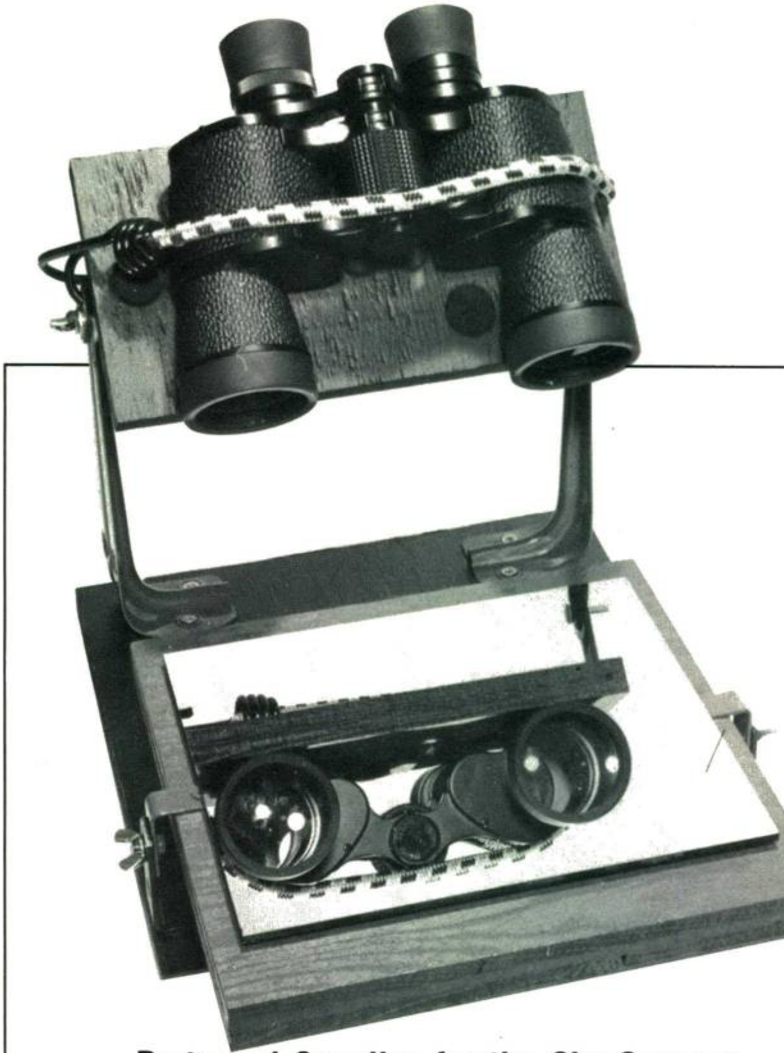
Equipment Atlas

# Build a Binocular 'Sky Scanner'

### by Bryan P. Shumaker



Because I enjoy viewing the sky with binoculars, I designed and built a simple mount I call the "Sky Scanner" to overcome the drawbacks of using binoculars. This mount fixes the binoculars so they don't shake and uses a mirror so you don't have to strain your neck.

Why use binoculars? One of the most enjoyable ways to view the night sky is with a pair of binoculars. Stars as faint as 10th magnitude are visible in 7x50 binoculars. Binoculars also have large fields of view that reveal great clouds of the Milky Way, numerous open clusters, and bright galaxies — large areas of sky that telescopes can't show. And binoculars have the advantage of portability: even a pair of large binoculars like 20x80s is far smaller and lighter than a telescope.

Despite these advantages, binoculars have one serious drawback: looking up for any length of time is very hard on your neck, shoulders, and arms, and as the strain on these parts of your body increases, holding binoculars steady becomes difficult. It's also virtually impossible to observe with someone else while using binoculars. Mounting binoculars on a tripod partially solves the problem, but neck and shoulder aches still result from always having to look up.

The Sky Scanner is simple enough to build in half an hour, and the parts cost less than $25. The device consists of three pieces of plywood, two shelf brackets, six angle brackets, a bungee cord, and a handful of bolts, screws, and wing nuts. It also requires a first-surface mirror, one that reflects light from the top surface and therefore provides a crisp image of stars without internal reflections.

The parts fit together to form an adjustable mount that holds the mirror and binoculars so you can sit down and look down through the binoculars comfortably. The mirror is mounted below the binoculars and reflects light from the sky above into the binoculars to focus at the binocular eyepieces. Because of this arrangement, you can observe comfortably with

## Parts and Supplies for the Sky Scanner

All of the parts and supplies listed below (except the mirror) are available from local hardware or sporting goods stores, but don't hesitate to use scrap materials. As you begin to visualize your specific Sky Scanner, you'll see the design is flexible enough to incorporate minor changes.

**Base board.** 9" by 9" plywood sheet, 1/2" to 5/8" thick.

**Mirror board.** 8" by 8" plywood sheet, 3/8" thick.

**Binocular support board.** 4" by 8" plywood sheet, 1/2" to 5/8" thick.

**Shelf brackets.** Two at least 6" long.

**Angle brackets.** Four, 1-1/2" to 2" on a side.

**Angle brackets.** Two, 1" on a side.

**Bolts, washers, and wing nuts.** Four sets to fit through angle brackets.

**Mounting screws.** Twelve to attach brackets onto wood pieces.

**Bungee cord.** To fasten binoculars to mount.

**Felt.** Self-adhesive strips or pads to protect binoculars from wood.

**Rubber feet.** Four, self-adhesive, to attach to underside of base.

**T-nut.** One, 1-1/4" to attach mount to standard tripod (optional).

**Silicone adhesive.** Small tube to affix mirror to mount.

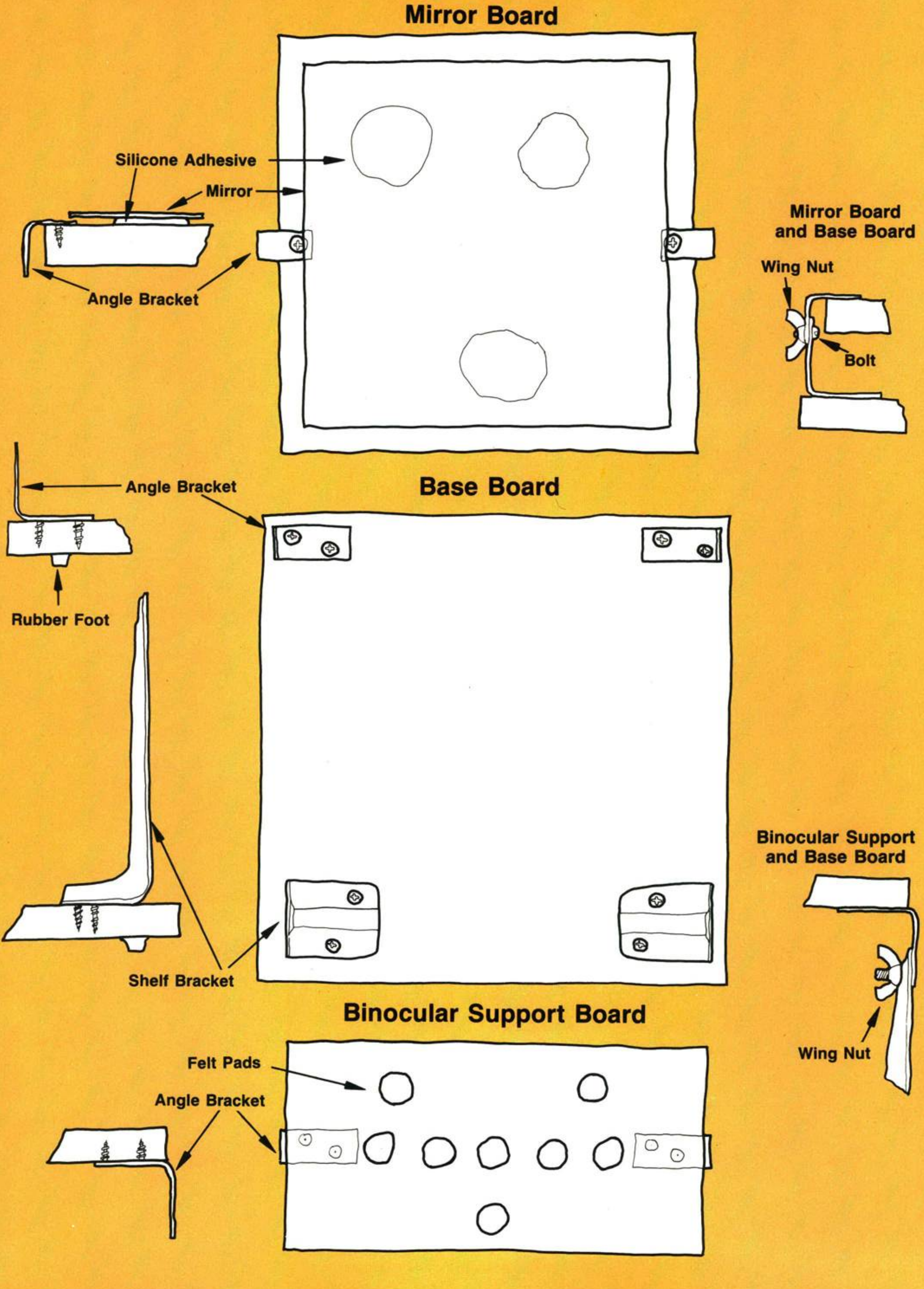
**First-surface mirror.** Size depends on binocular size; 7-1/4" by 6-1/4" seems fine for 7x50 binoculars.

**Drill.** For starting holes.

**Hacksaw.** For cutting shelf brackets to fit design.

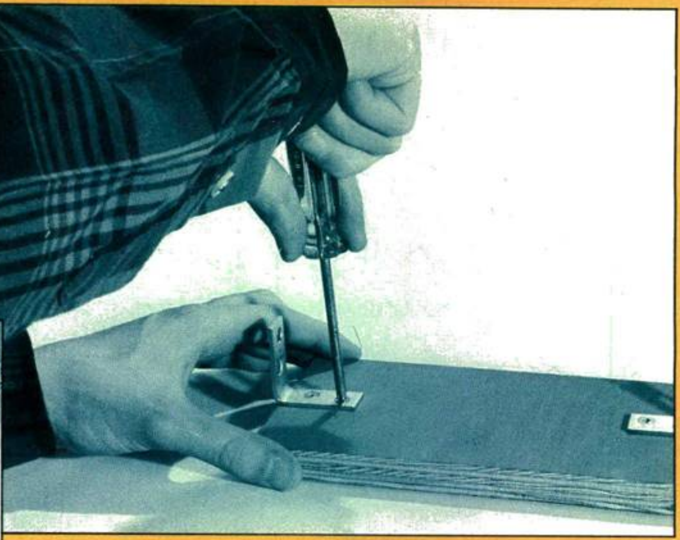
**Screwdrivers.** You may need flat-bladed and Phillips models.

# Holding the Binocular Sky Scanner Together

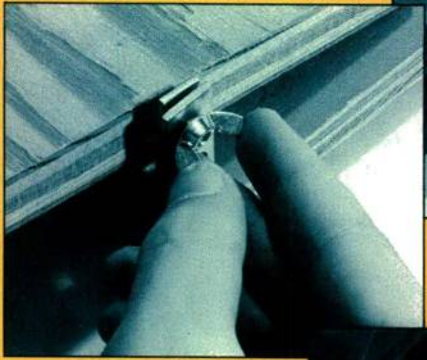


Mirror Board
Silicone Adhesive
Mirror
Angle Bracket
Mirror Board and Base Board
Wing Nut
Bolt
Base Board
Angle Bracket
Rubber Foot
Shelf Bracket
Binocular Support and Base Board
Wing Nut
Binocular Support Board
Felt Pads
Angle Bracket

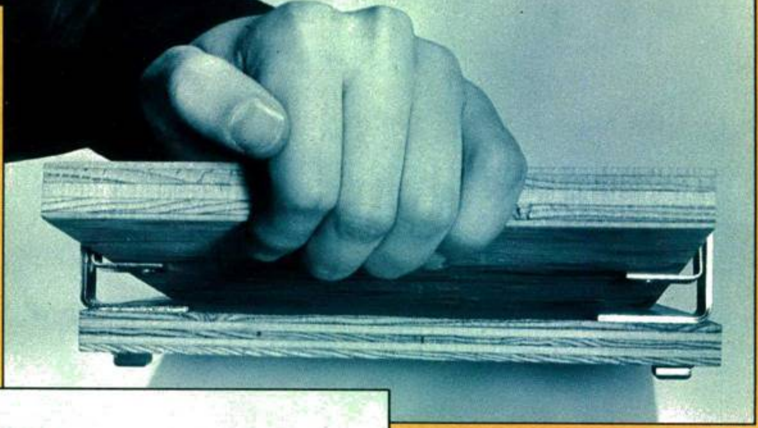
Assembling a binocular Sky Scanner is easy. The first step is to fasten angle brackets to the binocular support board (shown), the base board, and the mirror board.

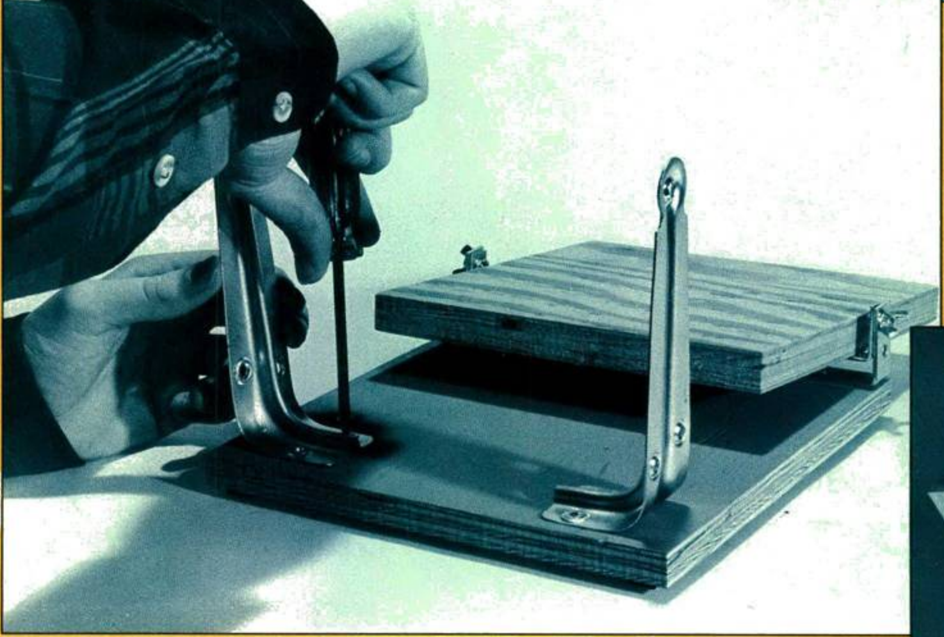


The mirror board rests on top of the base board, and the two are held together by a bolt and wing nut that clamps each angle bracket.

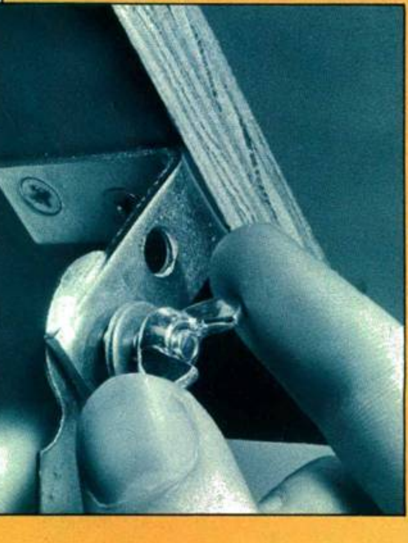


The angle brackets on the base board should allow the mirror board to tilt 15° or 20° each way so the device can show a large amount of sky.



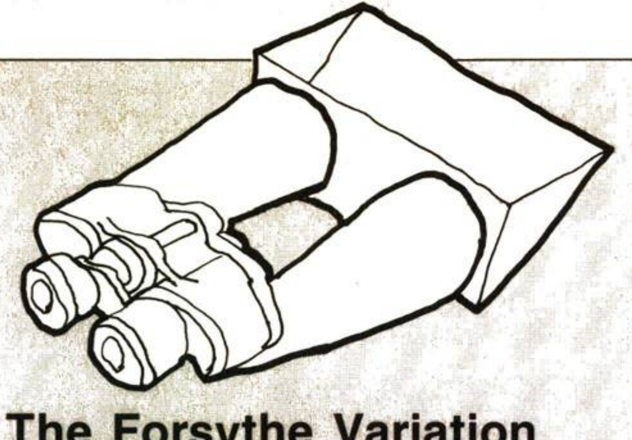


After the mirror board is attached, use screws to fasten shelf brackets to the base board that will hold the binocular support board.



Secure the binocular support board to the shelf brackets using a bolt, washer, and wing nut on each side.

All photos by Art Schmidt.



## The Forsythe Variation

If you own binoculars larger than 7x50s, consider building a variation of the Sky Scanner. The Forsythe device consists of a rectangular first-surface mirror mounted in a frame that fits snugly over the objective end of the binoculars. This provides a comfortable way of viewing the sky with large binoculars and requires only that you mount the binoculars on a tripod you can aim at different parts of the sky.

You can build the Forsythe device of heavy poster board, spray painted black to reduce reflections of unwanted light, but I recommend using light plywood for a more permanent device. First purchase a mirror that is wider than the width of the binoculars. Using bathtub caulk in 1/8"-thick blobs, glue the mirror onto a piece of heavy cardboard. Cut a cardboard piece with two holes that allow the binocular objectives to slip inside. Cut a bottom board — a strip of cardboard as long as the mirror board. And cut two angled side boards that, when assembled, tilt the mirror board to a 45° angle relative to the binocular's light path.

The rectangular frame must fit tightly over the retaining cells of both binocular objectives. If it is loose or slips, the device won't work effectively. Binoculars vary. You'll have to figure the dimensions for the frame to fit your binoculars or else the device may not work effectively.

Once you assemble the boards, add a 1/4" T-nut to the underside of the assembly and mount the assembly on a standard camera tripod. This will allow you to scan the sky by moving the tripod, and you'll be in a comfortable viewing position instead of a position that strains your neck.

*— C. Edward Forsythe*

the Sky Scanner in your lap, on a picnic table, on your car hood, or with a tripod. You no longer need to crane your neck to look up at the sky.

To make your Sky Scanner, first buy the parts from a hardware or sporting goods store. (See page 64 for a complete list of what you will need.) The first-surface mirror is the most difficult item to find, but a good selection is available from Edmund Scientific Co., 101 East Gloucester Pike, Barrington, NJ 08007. If you write this company, you will be sent a catalog of optical goods that includes first-surface mirrors. Begin your project by ordering the mirror. The mirror must be wider than the width of the binoculars and about twice the diameter of the objective in depth. The thickness isn't critical, but the mirror should be thick enough to withstand being transported.

The second step in constructing the Sky Scanner is to cut three pieces of plywood: a base board, mirror board, and binocular support board. The base board should measure 9" by 9" and about 1/2" thick. The mirror board should measure 8" by 8" and about 3/8" thick. The binocular support board should measure 4" by 8" and about 1/2" thick. Mount a small angle bracket on one edge of the mirror board so the bracket bisects the board. Use a mounting screw to attach the bracket so the mirror board rests in the angle. Do the same thing on the other side of the mirror board using another angle bracket.

Now attach the larger angle brackets to the smaller brackets on the mirror board with a bolt, washer, and wing nut. The smaller angle brackets should fit inside the larger ones. Lay this assembly against the base board so the larger brackets are almost at the end of the base board. Mark the positions of the larger brackets on the base board, disassemble the pieces, and mount these angle brackets to the base board so they line up with the marks you made. Reattach the mirror board and you should be able to move it up and down over the edge of the base board.

To create the binocular support board, attach small angle brackets to the underside of the board with the brackets connecting along the edge of the boards. Set this assembly aside for the moment.

Next you'll need to see how the shelf brackets fit onto the base board and then cut off part of the brackets because the brackets will probably be too long. Measure the amount you need to trim and cut the brackets with a hacksaw. Now mount the brackets onto the base board about six inches from the front of the board.

Mount the binocular support board on the shelf brackets on the base board. Make sure the shelf brackets and binocular support board assembly appear to be parallel with the mirror board. Good eyeball estimation should do the trick.

If you mount a 1/4" T-nut in the bottom of the base board about three inches from the front, you'll be able to mount the Sky Scanner on a standard photographic tripod. You don't have to mount the device on a tripod, however. If you want to set the Scanner on a flat surface, add rubber feet on the bottom of the base board to stabilize it and to keep it from scratching other surfaces. And you'll certainly want to add some felt to the top of the binocular support board to keep from scratching your binoculars on the wood surface.

When the basic unit is assembled, mount the mirror. To do this, place three dime-size lumps of silicone adhesive in a triangular pattern on the wood where the mirror will sit, mimicking a three-point mirror mount. Place 1/8"-thick cardboard stops underneath the mirror and place the mirror down on top of the adhesive. Allow the adhesive to cure in a well-ventilated place away from you. Make sure the mirror is mounted with the silvered side on top; if it isn't, you'll get double images caused by reflections inside the glass.

I suggest that you make a mirror cover to protect the delicate glass surface from dust and scratches. You could use scrap paneling, thin wood, or Plexiglas for this. To ensure the mirror's safety, attach four rubber feet to the mirror protector to keep the protector slightly above the surface of the mirror. The mirror cover can be held in place with an elastic bungee cord, rubber bands, or scrap Velcro material.

The binoculars rest on the binocular support board over the felt pads that sit on the wood surface. To keep the binoculars firmly in position, wrap a bungee cord around the binocular support board and hook the cord onto the angle brackets on the board's base. This should guarantee a snug fit that doesn't scratch or otherwise hurt the binoculars in any way.

When you're ready to take the Sky Scanner out under the stars, lay your binoculars onto the binocular support board, fasten the support board with the bungee cord, and tighten the wing nuts so that nothing will slip.

Using the Scanner is easy and fun once you get the hang of moving the mirror and binoculars to find objects in the sky. This takes about as long to get accustomed to as learning to use a finder scope does. You'll soon see that taking the strain out of using binoculars makes observing the sky a far more satisfying experience.

---

*Bryan P. Shumaker is a physician who lives in Bloomfield Hills, Michigan. His hobbies include telescope making and observing stars and deep-sky objects.*

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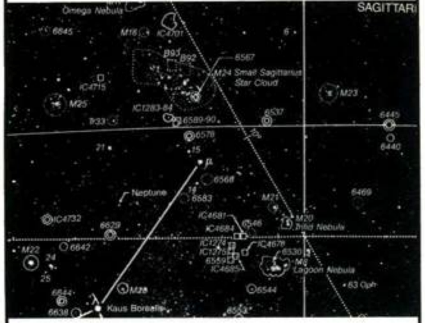
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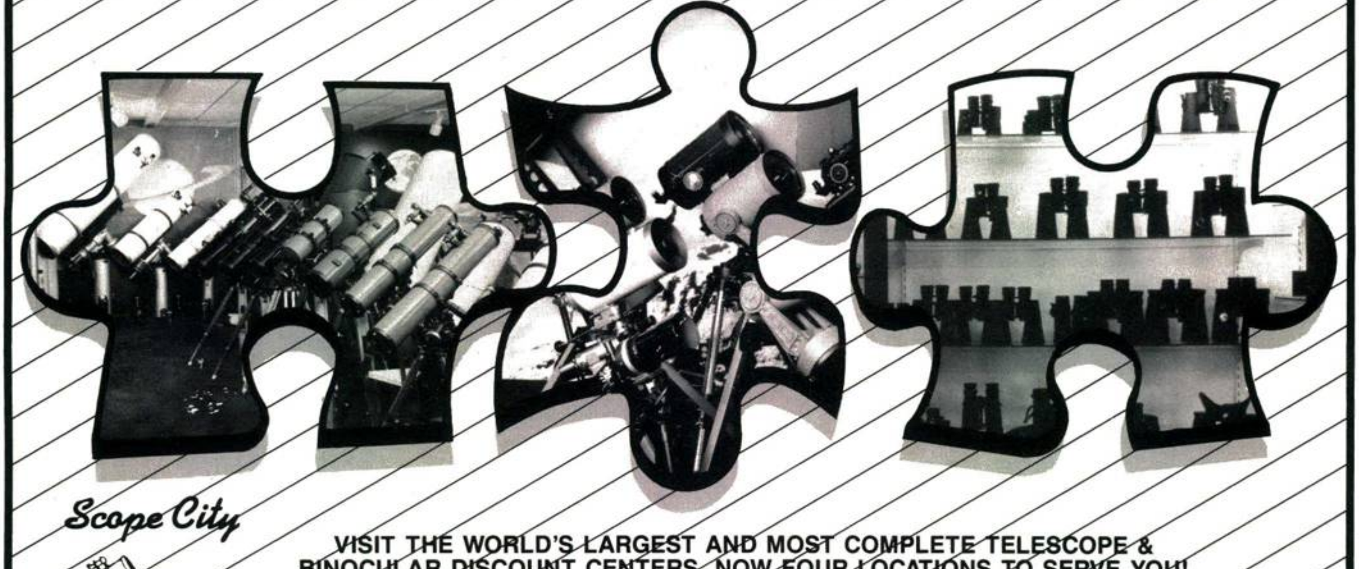

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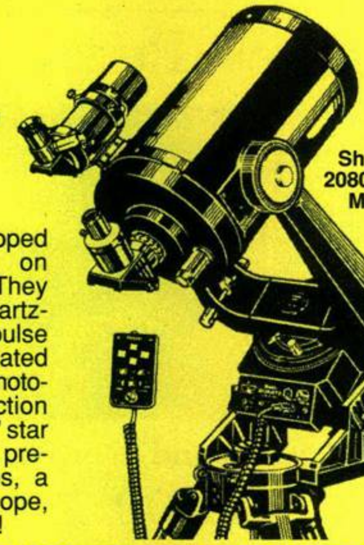
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| PIGGYBACK Bracket for camera, for 2080 | (List: $ 50.00) | **$ 36.95** |
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| T-Adapter for camera, for C8 Tubes | (List: $ 40.00) | **$ 29.95** |
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**SP-C8** .................. (List: $1,620) .......... **$ 949.95**

**SP-C8 StrBrt** ...... (List: $1,800) .......... **$1,099.95**

FREE FREIGHT! (UPS Ground) for the SP-C8's shown above

### Accessories for SP-C8 Telescopes

| | | |
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| 1-Axis DC MotorDrive/Corrector | (List: $ 220.00) | $149.95 |
| 2-Axis DC MotorDrive/Corrector | (List: $ 380.00) | $269.95 |
| 2-Axis DC SKYSENSOR Computer Drive/Corrector | (List: $ 950.00) | $599.95 |
| DEWSTAR LensShade/DewShield, for C8 Tubes | (List: $ 24.00) | $ 19.95 |

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# Reviews

## *Uranometria 2000.0*: Limited by Its Sources

*Uranometria 2000.0*, volume I: The Northern Hemisphere to −6°, by Wil Tirion, Barry Rappaport, and George Lovi, (Willmann-Bell, Inc., 1987), ISBN 0-943396-14-X, 262 pages, $39.95.

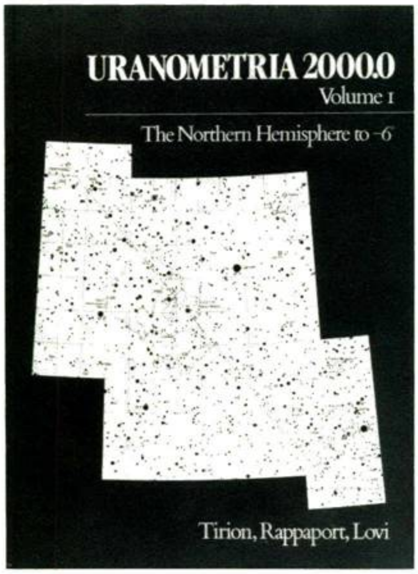
Sometimes the best thing about a bottle of wine is the price: though the quality of all the wine's attributes is only fair to good, the wine is an excellent value at $40. The analogy is apt for *Uranometria 2000.0*.

Unlike most earlier atlases, the charts in *Uranometria 2000.0* are conveniently small and presented in book form. The present work matches the size and thickness of the two-volume *Sky Catalogue 2000.0*, published by Sky Publishing, which makes a good companion to this atlas. The charts cover declination strips usually 11° wide; a handy hemispheric chart index in the back of the book helps you locate the chart you want to use. For the general observer, the atlas is handy, well designed, and well priced. But for serious observers, there are problems.

The star list for this atlas was drawn from the venerable *Bonner Durchmusterung (BD)*, published in 1863. Hence, though promotional copy for *Uranometria 2000.0* may state the coordinates are for epoch 2000, the star positions are for epoch 1855! The *BD* star positions aren't all that great by contemporary standards, and one wonders what 150 years of proper motion has done to reduce the accuracy of star positions in *Uranometria 2000.0*. To be sure, the authors corrected egregious cases of large proper motion. Still, for me at least, a nagging uncertainty remains.

To assuage my own doubts, I compared large regions of the sky on *Uranometria 2000.0* star by star with the *Atlas Borealis* of Becvar. Modern precision star catalogs were used as the source for the Becvar atlases rather than the *BD*, and about 300,000 stars were plotted in *Atlas Borealis*, compared to around 330,000 in *Uranometria 2000.0*. I found eight tight groups of stars that seemed significantly different in the two atlases.

I next compared these star groups with Palomar Observatory Sky Survey prints. Does the lower accuracy of the *BD* affect the geometry of star patterns? In five cases both charts were correct: the different patterns resulted from a "selection effect" of fainter stars included or omitted. In two cases — both very close overlapping pairs of stars as plotted on the atlases — the *Atlas Borealis* was off. In the final case, a star was misplotted on *Uranometria 2000.0* (the variable star RY Lyrae). From this sample it is reasonable to conclude that both atlases are sufficiently accurate: the *Atlas Borealis* used precise star positions plotted by hand, whereas *Uranometria 2000.0* uses lower-precision star positions plotted by machine.



Another problem is that stellar magnitudes in the *BD* catalog have a well-known scale error at the faint end. F. W. A. Argelander, who compiled the *BD*, assumed a magnitude limit of 9.5, though his 3-inch transit telescope reached much fainter. Thus stars as faint as magnitude 12 or so are all listed as magnitude 9.5 in the *BD* catalog. To avoid plotting stars with incorrect magnitudes, the *Uranometria 2000.0* compilers omitted all stars listed in the *BD* fainter than magnitude 9.3 to achieve a relatively uniform brightness limit. Ironically, this brings the star list down to near that of twentieth-century precision star catalogs such as the third *Astronomische Gesellschaft Katalog (AGK3)*.

If the *BD* had been abandoned, the maps could have been drawn to higher precision, taking proper motions into account for every star. There would indeed be a penalty in sheer star count but only in about 10 percent over the whole sky (the *AGK3* actually has about 20 percent more stars than the *Uranometria 2000.0* in the Northern Hemisphere).

In his introductory essay to *Uranometria 2000.0* George Lovi described the effort to maintain a smooth magnitude cutoff and complained about the ragged incompleteness limit of the Becvar atlases, which dip irregularly in certain zones to magnitude 13 or 14. As a deep-sky observer who uses the Becvar atlases, I *welcomed* the higher density of stars wherever it occurred. The *Uranometria 2000.0* compilers would probably have included those faint *BD* stars but could not, because the magnitudes of those stars are wonky; Becvar had magnitudes, proper motions, and spectral types for even the faintest stars out of the modern catalogs.

The authors erred in not using primary source catalogs for information on variables, double stars, and deep-sky objects. From my comparison between the *Atlas Borealis* and *Uranometria 2000.0*, I found twenty variable stars that are plotted in *Uranometria 2000.0* but not labeled as such. All of them were at the faint end of the magnitude scale. Apparently the compilers used the variable star list out of *Sky Catalogue 2000.0*, volume 2 *(Sky Cat 2)*, so few variables fainter than magnitude 8 are labeled. I'll bet that hundreds of variables are left unmarked. The third edition of the *General Catalogue of Variable Stars* (vintage mid-1970s) is available in machine-readable form, so why was there no computer search to match up *BD* numbers?

A similar problem seems to exist with the doubles (lots of faint ones are unmarked), perhaps for the same reason. The variable U Cephei (for which a variable name is marked) is not noted as a double — *Sky Cat 2* shows it to be ADS 830. Looking at the *Atlas Borealis*, we see that ADS 830 has three components, one of which is a spectroscopic binary, and the differing spectral types of the latter are indicated in color. The Becvar atlases may have their drawbacks, but they contain more stellar information than *Uranometria 2000.0* does.

For deep-sky objects, the *Sky Cat 2* selection is augmented by the *Revised New General Catalogue (RNGC)*. As has been pointed out many times, the *RNGC* contains many errors, and these, unfortunately have been faithfully transferred to the atlas. Thus, the spiral galaxy NGC 3999 in the NGC 4000 group (chart 147) is misplotted because of an *RNGC* error; there is a similar mixup in the NGC 6962 group (chart 254). Many perfectly good open clusters listed as class 7 in the RNGC are also omitted in *Uranometria 2000.0*. (NGC 1798 in Auriga northwest of Capella is an example.)

Using catalogs as sources can also lead one astray. Near Capella (chart 66) are plotted two overlapping open clusters, King 22 and Berkeley 18 (they actually correspond to a single object), likewise for NGC 1857 and Czernik 20 (same chart), and NGCs 1746, 1750, and 1758 (charts 134 and 135). The cluster Collinder 21 (charts 92 and 128) is misplotted because of a position error in the source catalog: it is the small circlet of stars just to the south.

The *RNGC* should not have been used as a source. Galaxies (which make up 90 percent of the deep-sky objects) could have been selected from the *Uppsala General Catalogue (UGC)*, which provides angular dimensions and position angles for 12,000 galaxies. This way galaxies could have been plotted with their sizes and orientations explicitly on the sky rather than with the uniform horizontal oval that represents all but the bright Shapley-Ames galaxies. Because size corresponds very well with brightness, most of the galaxies would be tiny, but I believe this would be better than using misleadingly large symbols for overly faint galaxies. This is not a necessity, but it would have been a nice touch. What's more, use of the *UGC* (and its southern counterparts) would have allowed the inclusion of brighter IC objects. Some rich Abell galaxy clusters on the star atlas are distorted by the absence of IC objects — in the Perseus cluster, for instance, where IC 310 ranks among the brightest few members. Special large-scale inserts covering several galaxy clusters would have been another nice touch — better certainly then the utterly indecipherable mess of the Coma cluster (chart 149 and adjoining).

*Uranometria 2000.0* is undoubtedly a boon to the average deep-sky observer. But the atlas is a disappointment for the dedicated observer because it mirrors the faults of the astronomical catalogs on which it is

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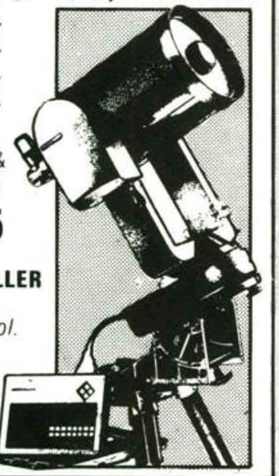

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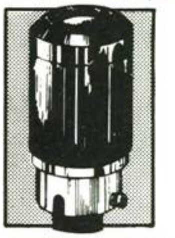

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based. As minor as a few mislabeled stars, unplotted star clusters, and misplaced galaxies might seem, such weaknesses have a nasty habit of impairing serious observing. Perhaps the ultimate atlas will have to wait for the ultimate astronomical catalog.

— *Brian Skiff*

## *Uranometria 2000.0*: A Landmark Atlas

My first comment upon seeing *Uranometria 2000.0* was: "It's about time!" This is the first sky atlas that gives comprehensive coverage of the sky and includes most types of deep-sky objects. *Uranometria 2000.0* may not seem like much of a change from *Sky Atlas 2000*, which plotted most stars brighter than 8th magnitude, but it reaches that one-and-a-half crucial extra magnitudes deeper to show all the stars you can see in a typical 6x30 finder scope.

Furthermore, the large scale of this atlas has made plotting details of certain regions of sky convenient: for example, individual members of Stephan's Quintet are plotted. The Northern Hemisphere volume has 259 separate maps, together with two "finder maps" comprised of conventional stick-figure constellations superimposed on a grid denoting which individual map applies. Charts overlap each other enough to make identification of objects easy.

The name *Uranometria* is borrowed from a great atlas by Johann Bayer that set the standard for accuracy and excellent graphic style early in the seventeenth century. Bayer is best remembered as the first person to apply Greek letters as stellar designations. We honor Bayer when we use the term Alpha Andromedae for the star Alpheratz or even Alpha Centauri instead of the old designation Rigil Kentaurus.

Previous maps had the large scale or the large number of stars or the range of objects, but no one map had them at the same time. Only two available to the general public even approach *Uranometria 2000.0* in complexity: *The Smithsonian Astrophysical Observatory Star Atlas of Reference Stars and Nonstellar Objects* and its derivation the *American Association of Variable Star Observers Variable Star Atlas*. Something George Lovi pointed out in the introduction was previously unknown to me — that the SAO atlas was flawed for visual observers because it only included stars for which proper motion data existed. In any case, it didn't label the NGC entries because they were not used for the purposes the SAO was designed for. Another disadvantage was that looking at the SAO was a strain to the eyes, because the lines were too delicate. The AAVSO atlas was printed larger but had fewer NGC entries — again not labeled.

The richness inherent in *Uranometria 2000.0* is astonishing. Go to your favorite portion of the sky and there you will find not only your favorite objects but a rich background of lesser NGC objects as well as objects taken from other catalogs. For example, NGC 7331 is plotted surrounded by its cloud of neighboring galaxies. Many quasars are plotted as well as variable stars. Large and bright emission nebulae are drawn in. The Veil Nebula is a full two inches across. Large galaxies are drawn in with elongation and scale intact. Of course, this luxury of scale comes with a price: you can't merely look at a page and tell where you are. The Big Dipper requires five maps! A "finder" atlas is necessary much in the same manner as a finder telescope is needed for a telescope.

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the page, you may have to look half the book away, but the map number is right there to guide you. The maps are bound into a volume so you cannot lose them, but the book lies flat and stays open at the selected page. The paper is of high-quality stock, but the pages have apparently not been waterproofed, so care should be taken to avoid excessive dewing.

Some errors in the *Revised New General Catalog (RNGC)* have been propagated in this atlas, but the list of errors is small. If the atlas has a weakness, it's the haphazard criteria for including dark nebulae. A quick once-over revealed no Barnard objects, except for named objects like the Horsehead Nebula. My favorite Barnard objects are B142 and B143 near Gamma Aquilae. They were absent. Inexplicably, other less observable dark nebulae from less famous catalogs seem to be plotted.

My only complaint about the format is that the map numbers use a "left-hand thread." Had the map numbers increased in a westerly direction rather than easterly, the two maps on either leaf of the open book would have defined a roughly contiguous area of sky. Perhaps this was tried and rejected, but I think it would have made the atlas easier to use.

I can't wait until the southern half of the atlas (volume II) appears. Volume I goes to −6° declination, and thus only the northern half of the sky has appeared so far. Volume II is in the works and will appear soon. Some people might speculate that a pecuniary motive induced the publisher to split the sky in this manner. I think the answer is much simpler. If the sky was covered down to −50° in one volume, the number of charts would increase by 156. The additional thickness would make the atlas less likely to lie flat, and those living in Florida would still need to purchase the southern atlas.

In any case, Willmann-Bell has done a real service to amateur astronomy by producing this atlas. The publisher has also upped the stakes in making future atlases, much the same way Johann Bayer did when he produced the first great star atlas, the original *Uranometria*, in 1603.

This is an atlas that will stand as a high watermark for many years to come. It is a work so huge that it is daunting to any who would attempt to surpass it.

*— Dick Suiter*

## Biography and History

*Seven Ideas That Shook the Universe* by Nathan Spielberg and Bryon D. Anderson, (John Wiley & Sons, Inc., 1987), ISBN 0-471-84816-6, paperback, 263 pages, $14.95.

## Galaxies

*The Galaxy*, edited by Gerry Gilmore and Bob Carswell, (D. Reidel, 1987), ISBN 90-277-2545-4, hardcover, 435 pages, $89.

*Nearly Normal Galaxies: From the Planck Time to the Present*, edited by S. M. Faber, (Springer-Verlag, 1987), ISBN 0-387-96521-1, hardcover, 464 pages, $35.

## General Astronomy

*The Cosmos from Space* by David H. Clark, (Crown Publishers, Inc., 1987), ISBN 0-517-562456, hardcover, 176 pages, $14.95.

*The Inner Limits of Outer Space* by John C. Baird, (University Press of New England, 1987), ISBN 0-877451-406-1, hardcover, 256 pages, $18.95.

*The Mind-Boggling Universe: A Dazzling Scientific Journey through Distant Space and Time* by Neil McAleer, (Doubleday, 1987), ISBN 0-385-23039-7, paperback, 245 pages, $8.95.

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## Photography

*Astrophoto VII: Seminar Proceedings*, (Orange County Astronomers Publications, 2215 Martha Avenue, Orange, CA 92667, 1987), paperback, 63 pages, no price given.

## Physics

*Einstein's Legacy: The Unity of Space and Time* by Julian Schwinger, (Scientific American Books, Inc., 1986), ISBN 0-7167-5011-2, hardcover, 250 pages, no price given.

*The Ring of Truth: An Inquiry into How We Know What We Know* by Philip and Phylis Morrison, (Random House, 1987), ISBN 0-394-55663-1, hardcover, 255 pages, $24.95.

## Space

*Envoys of Mankind* by George S. Robinson and Harold M. White, (Smithsonian Institution Press, 1986), ISBN 0-87474-820-8, hardcover, 292 pages, $19.95.

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*— Kristine R. Majdacic*

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*Stellar Pulsation*, edited by A. N. Cox, W. M. Sparks, and S. G. Starrfield, (Springer-Verlag, 1987), ISBN 3-540-17668-3, hardcover, 422 pages, $40.60.

## Textbooks

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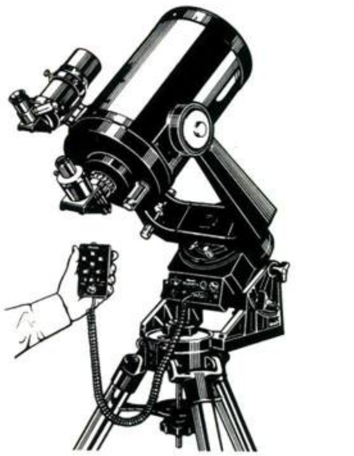

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# AstroNews

## Brown Dwarf Orbits Nearby Star

A new type of object, a brown dwarf, orbits the nearby white dwarf star Giclas 29-38, according to astronomers Ben Zuckerman and Eric Becklin. The astronomers from UCLA and the University of Hawaii, respectively, came to this conclusion after finding telltale infrared emission from the Giclas 29-38 system. This is the first brown dwarf to be detected with reasonable certainty.

Zuckerman announced the discovery at the nineteenth annual meeting of the Division of Planetary Sciences of the American Astronomical Society on November 10, 1987, in Pasadena, California.

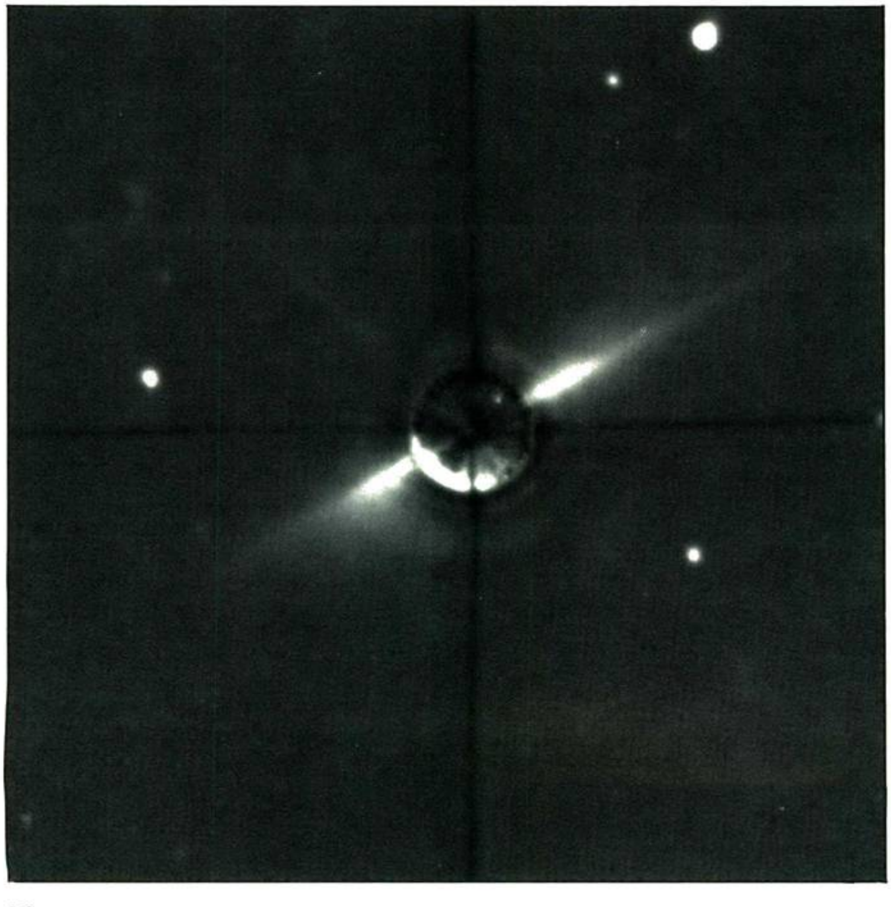
"Brown dwarf" is the nickname astronomers give to objects that lie between stars and planets. On one hand, the objects are too small and cold to sustain thermonuclear reactions in their cores and hence qualify as stars. But on the other hand, they are too large and hot to be called planets, at least in the usual sense of a small, cold body, because brown dwarfs radiate heat left over from their formation for billions of years.

The "parent" star, Giclas 29-38, is a white dwarf that lies 46 light-years from the Sun. This tiny, dying star exhausted its nuclear fuel some 600 million years ago and collapsed into a small, hot body. With a surface temperature of 11,500 kelvins, G29-38 gives off very little infrared light of its own. Thus a strong peak in the infrared part of the spectrum was an immediate tip-off that G29-38 was not alone. The radiation accounts for 2.5 percent of the energy given off by the G29-38 system.

Zuckerman rejected any possibility that the infrared measurements could be in error. "It's got a huge infrared excess. We're sure the result isn't going to go away," he said.

After considering a variety of hypotheses for the infrared excess, Zuckerman and Becklin proposed a brown dwarf companion with a temperature of 1,200 kelvins as the most likely explanation. If they are correct, the object has a mass between 0.04 and 0.08 times that of the Sun and a radius 0.15 that of the Sun.

Although Zuckerman has considered alternate explanations for the infrared excess, "a brown dwarf is the most natural explanation. All of the others are



## Beta Pictoris Disk Is Bigger, Asymmetric

**The disk of dust around the nearby star Beta ($\beta$) Pictoris is both larger and less symmetrical than originally thought. New images taken with the 2.5-meter duPont telescope at the Las Campanas Observatory in Chile by Bradford Smith and Richard Terrile show that the disk, which we see nearly edge-on, is twice as large as the discovery images showed it to be. To record the disk, the scientists from the University of Arizona and JPL, respectively, must block the light from the central star. The disk, possibly a developing planetary system, extends 1,100 astronomical units (AU) to the northeast of the star and some 900 AU to the southwest. The star's optical and infrared spectra suggest the star is made of dust- to baseball-sized particles of ice and rock.**

pretty unlikely," he said.

The star might have a companion star with strong infrared emission, such as a dusty M star, but class M stars are much hotter and brighter than the observations suggest the companion object is. Or G29-38 might lie in front of a distant galaxy, though the probability of this happening is extremely low. If G29-38 lies in front of a distant infrared source, however, G29-38's proper motion will move it sufficiently far within six months to disrupt the alignment.

Another possibility is that a warm, circumstellar disk emits the infrared signal. Zuckerman considers this unlikely. "This white dwarf went through its red giant phase some 600 million years ago," he explained, "and that would have eliminated dust, asteroids, planets, and so on. They wouldn't have survived."

Photographs showed that the infrared source must lie less than half of one arcsecond from the white dwarf, corresponding to a separation of less than 7 astronomical units at G29-38's distance. The orbital period of the brown dwarf is unknown: it could range from just a few hours to many years.

Detecting radial velocity shifts in the spectrum of the white dwarf — the next logical step in investigating the system — will be difficult. "G29-38 is a ZZ Ceti type star, a star that pulsates. Unfortunately it undergoes very complex pulsations, so it will be hard to disentangle the radial velocity shifts produced by the brown dwarf," Zuckerman explained.

Zuckerman jokingly proposed that the infrared excess could be caused by LGMs, or "little green men."

"It's just the sort of spectral signature you'd expect to see from a Dyson sphere," he said. "The civilization would capture starlight for power and radiate waste energy in the infrared. But a brown dwarf is a far more likely explanation."

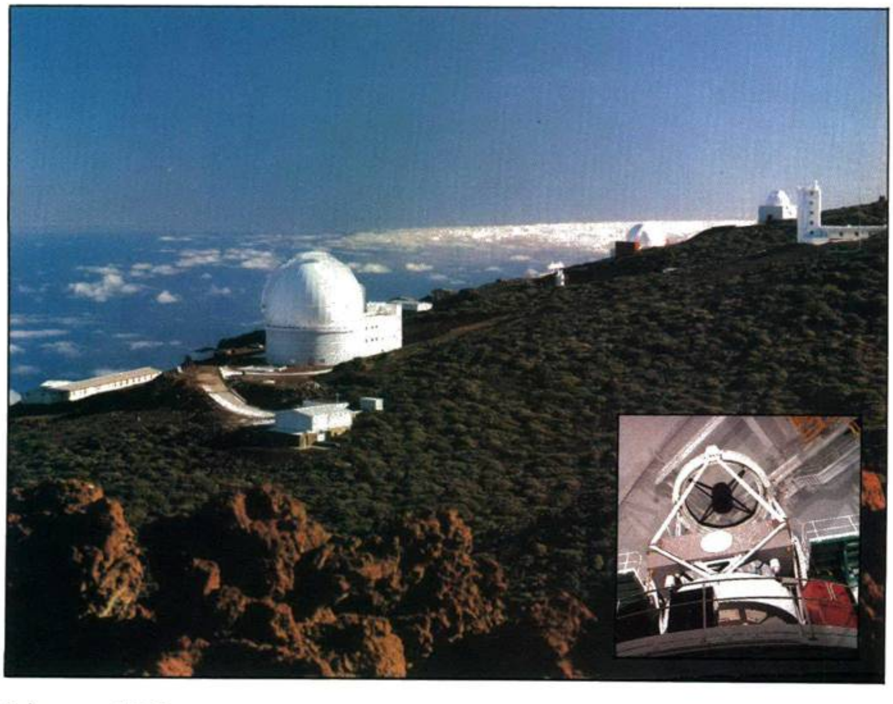
## 4.2-Meter Herschel Telescope Now Open

The 4.2-meter (165-inch) William Herschel Telescope (WHT) officially opened in October 1987 at La Palma in the Canary Islands. Initial observations show that the world's newest telescope is also the most powerful, capable of seeing farther into space than any other optical telescope.

The 4.2-meter-diameter primary mirror makes the WHT the third largest single-mirror optical telescope in the world. And the excellent observing conditions at La Palma give the WHT an advantage over its two larger rivals, the 5-meter Hale Telescope on Palomar Mountain and the Soviet 6-meter telescope.

The Herschel telescope is operated jointly by the United Kingdom and the Netherlands (the Netherlands contributes 20 percent of the funding). The telescope joins several other telescopes at the Spanish Roque de los Muchachos Observatory on La Palma, a small island at the western end of the Canary Island chain. The observatory is situated on the northern edge of a volcanic caldera some 8,000

**The 4.2-meter William Herschel Telescope is now operating on the Canary Island of La Palma. The dome of the Herschel Telescope (left foreground) joins the domes of the Isaac Newton Telescope and the Jacobus Kapteyn Telescope, and a Swedish solar tower at the Roque de los Muchachos Observatory. Inset: The William Herschel Telescope inside its dome. Photos courtesy Royal Greenwich Observatory.**



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feet above sea level. The site lies above the clouds most of the time and above the atmospheric inversion layer that keeps most water vapor and dust in the lower atmosphere. The island location also offers very steady seeing, and La Palma is not heavily populated or a major tourist attraction so the skies are dark.

The WHT has a state-of-the-art design that affords the British, Dutch, and Spanish astronomers additional advantages. The most important feature is the telescope's altitude-azimuth mounting. This mounting has significant operational advantages over an equatorial mounting and was also cheaper to build. The difficult task of tracking objects across the sky is handled by an advanced computer-controlled system. The mounting also allows a relatively small dome to enclose the telescope, which minimizes air currents in the dome that can distort the normally sharp images produced by the telescope.

The large diameter and excellent location of the Herschel Telescope means the telescope is particularly well suited for studying distant and faint objects. Astronomers plan to make observational cosmology one of the leading research themes with the new telescope, a fitting tribute to the founder of observational cosmology, William Herschel.

## Internal Ice Key to Miranda's Surface?

Uranus' strange moon Miranda may consist of a special form of ice that caused the moon's apparent volcanic and tectonic resurfacing. University of Arizona planetary physicist Steven Croft believes the ice formed as a direct result of the low temperature at which Miranda condensed from the solar nebula near Uranus. Croft presented the theory at the annual meeting of the Geological Society of America held in Phoenix last October.

The images of Miranda returned by the *Voyager 2* spacecraft two years ago shocked planetary scientists. Only 300 miles across, Miranda should be a geologically dead, heavily cratered world, because it is too small to generate the internal heat needed to resurface its original terrain.

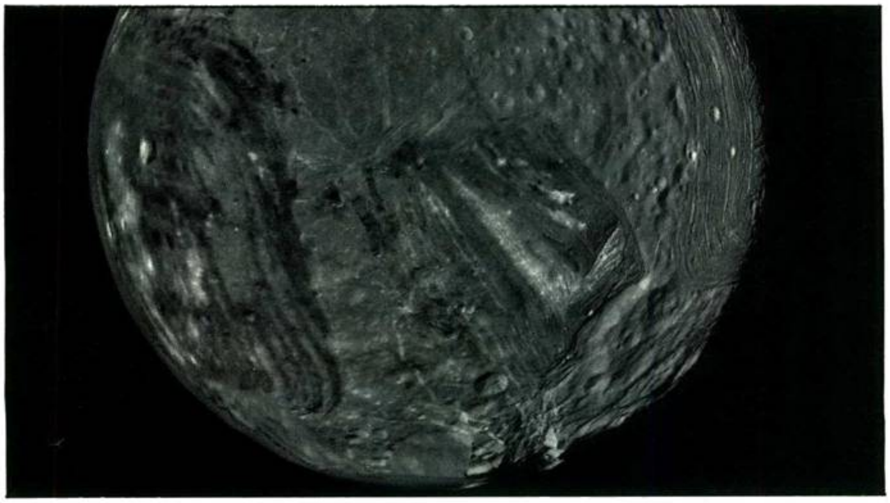
The *Voyager* images told a radically different story. Miranda does have craters, but overall the satellite's surface is a bizarre mixture of geologic features. The tiny moon is crossed by an enormous network of canyons, each typically 19 to 25 miles wide and 2 to 3 miles deep. Canyons in this network cross at nearly right angles to one another. A second system of canyons follows the curve of a 186-mile-diameter impact crater.

Planetary scientists have proposed several theories to account for Miranda's unusual surface. Some believe Miranda once broke up in a collision with another object and later reaccreted. Croft argues that the probability of such a collision is low, however.

Others believe the canyons formed when Miranda expanded during a long period of internal heating. The *Voyager* images also show evidence of volcanism and tectonic activity — such as three depressions in the older cratered terrain that are filled with a stiff magma — both are signs of an internal source of heat.

Richard Greenberg and Robert Marcialis of the University of Arizona propose that the heat resulted from tidal forces caused by Miranda's tumbling motion. They theorize that Miranda originally orbited Uranus in an eccentric orbit. At some point a large irregularity — perhaps the 186-mile-diameter crater — formed on Miranda's surface and caused the satellite to tumble chaotically. The tumbling produced tidal stresses that heated the interior and also allowed Miranda's orbit

**The surface of Uranus' moon Miranda consists of two radically different types of terrain: an old, heavily cratered terrain, and a young, complex terrain. The young terrain, shown in the oval regions at right and left and in the distinctive "chevron" feature at center, may be the result of resurfacing caused by the unusual nature of Miranda's ices. NASA/JPL photo.**



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| | | 63-1030 Drive Corr | 119.95 |
| 63-1052 Porro Prism | 39.95 | Tripod & Wedge 4000 | 99.95 |
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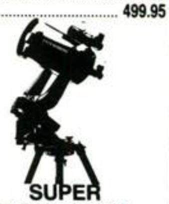

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to decay to its present circular orbit.

Croft, on the other hand, believes the peculiar composition of Miranda's ices caused the satellite's interior to melt. At the extremely cold temperatures where Miranda formed, methane and water ice combine to produce a compound known as a clathrate, in which the crystal structure of the water ice traps methane inside. The compound is unusual because it is a very poor conductor of heat.

Croft says that if Miranda formed at a low enough temperature, it would consist of rock mixed with 50 to 60 percent of this methane clathrate and some ammonia-water ice. Because the methane clathrate conducts heat so poorly, the heat produced by radioactive decay would by itself raise Miranda's internal temperature to at least −143° Fahrenheit, the melting point of ammonia-water ice. The ammonia-water mixture would then flow as magma through fissures to the moon's surface. The magma-filled depressions revealed in *Voyager* images support this theory.

## ASTRONOMY
## AstroCalendar

**January 10-14**
**171st Meeting of the American Astronomical Society** (professional meeting sponsored by the University of Texas at Austin and McDonald Observatory), Austin, Texas. Contact: American Astronomical Society, 2000 Florida Avenue, NW, Suite 300, Washington, DC 20009.

**January 16**
**3rd Annual Astronomy Day** (sponsored by Patterson Planetarium and Callaway Gardens), Callaway Gardens outside Columbus, Georgia. Contact: Carole Rutland Groce, Patterson Planetarium, 2900 Woodruff Farm Road, Columbus, Georgia 31907. Phone: (404) 568-1730.

**January 16-17**
**Astronomy Weekend** (telescope fair, observing, exhibits, sponsored by the Louisville Astronomical Society and the Louisville Museum of History and Science), Louisville, Kentucky. Contact: Alan Goldstein, Museum of History and Science, 727 West Main Street, Louisville, KY 40202. Phone: (502) 589-4584.

**January 16-18**
**Stardate '88** (observers convention), Cape Egmont Observatory, New Plymouth, North Island, New Zealand. Contact: David Coppart, P.O. Box 811, Whangarel, New Zealand.

**February 7**
**Mars Watch '88** (co-sponsored by the Planetary Society in cooperation with the Lawrence Hall of Science), University of California at Berkeley, Berkeley, California. Contact: Planetary Society, 65 North Catalina, Pasadena, CA 91106. Phone: (818) 793-5100.

**February 18-21**
**IAPPP Symposium: New Generation Small Telescopes,** Lazy K Bar Ranch, Tucson, Arizona. Contact: Russell M. Genet, Fairborne Observatory, 1357 North 91st Place, Mesa, AZ 85207. Phone: (602) 986-2828, (602) 297-0702 for reservations.

**February 18-21**
**4th Annual Winter Star Party** (sponsored by the Southern Cross Astronomical Society), Florida Keys, Florida. Contact: Tippy D'Auria, 1051 N.W. 145th Street, Miami, FL 33168. Phone: (305) 685-6001.

**May 27-30**
**Riverside Telescope Makers Conference,** Camp Oakes, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Avenue, Riverside, CA 92503. Phone: (714) 689-6893.

**June 25-26**
**The Universe in the Classroom** (weekend credit workshop on teaching astronomy in grades 3-12 for U.S. and Canadian teachers, sponsored by the Astronomical Society of the Pacific and the Royal Astronomical Society of Canada), University of Victoria, Victoria, British Columbia, Canada. Contact: Teachers Workshop, A.S.P., 1290 24th Avenue, San Francisco, CA 94122.

**June 25-July 2**
**100th Annual Meeting of the Astronomical Society of the Pacific, jointly sponsored by the Royal Astronomical Society of Canada and the Western Amateur Astronomers,** University of Victoria, Victoria, British Columbia, Canada. Contact: A.S.P., Summer Meeting Department, 1290 24th Avenue, San Francisco, CA 94122.

**July 27-30**
**ALCON, the 1988 Astronomical League Convention jointly sponsored by the Association of Lunar and Planetary Observers,** Iowa Western Community College, near Omaha/Council Bluffs, Nebraska. Contact: George E. Allen, 3390 South 130th Street, Omaha, NE 68144. Phone: (402) 333-1097.

*AstroCalendar notices must be submitted at least four months in advance of the date of the event.*

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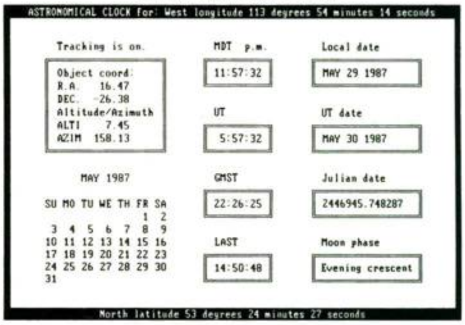

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 R.A.    16.47
 DEC.   -26.38            UT               UT date
 Altitude/Azimuth
 ALTI     7.45             5:57:32         MAY 30 1987
 AZIM   158.13

       MAY 1987           GMST             Julian date

 SU MO TU WE TH FR SA     22:26:25         2446945.748287
                    1  2
  3  4  5  6  7  8  9     LAST             Moon phase
 10 11 12 13 14 15 16
 17 18 19 20 21 22 23     14:50:48         Evening crescent
 24 25 26 27 28 29 30
 31

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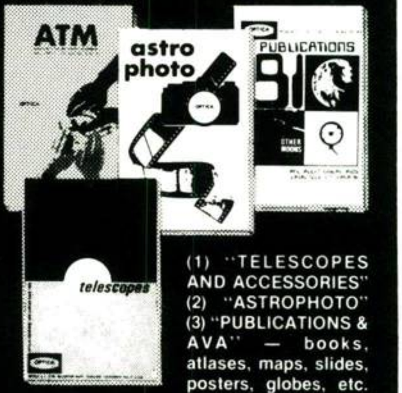

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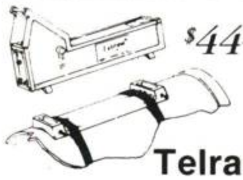

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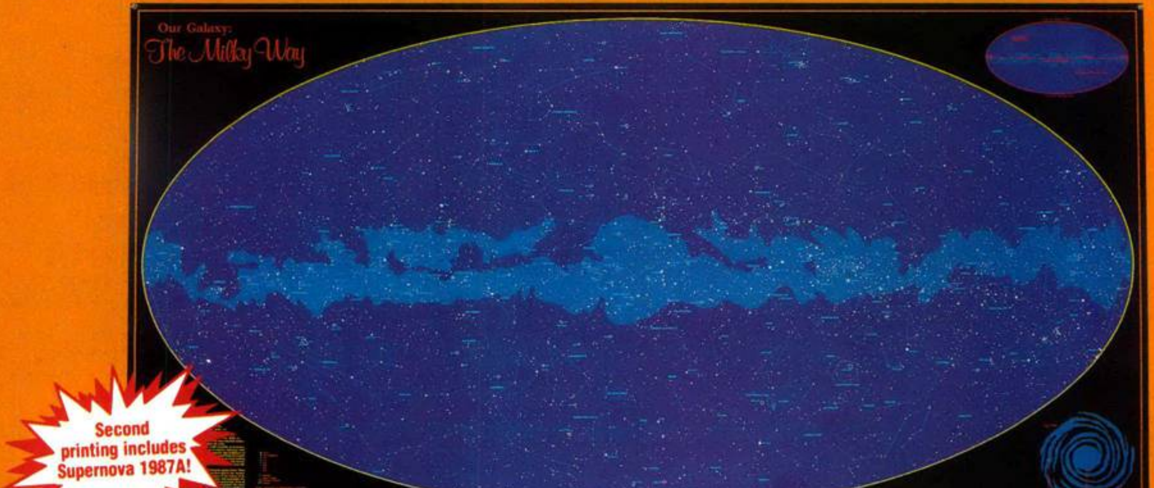

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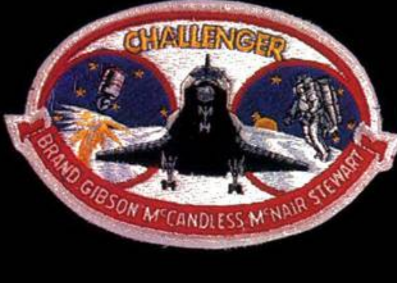
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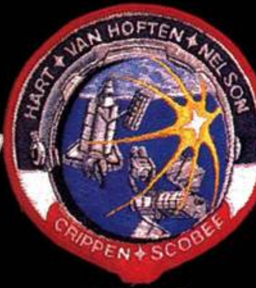
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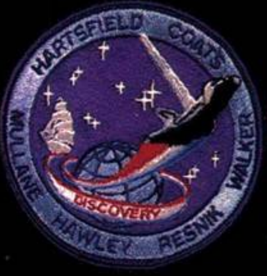
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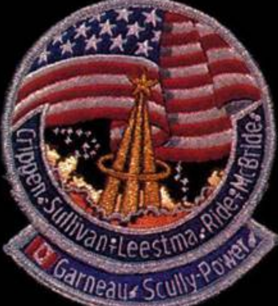
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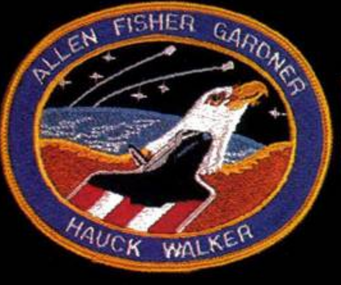
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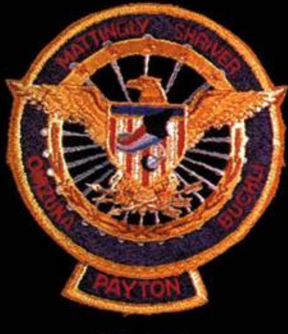
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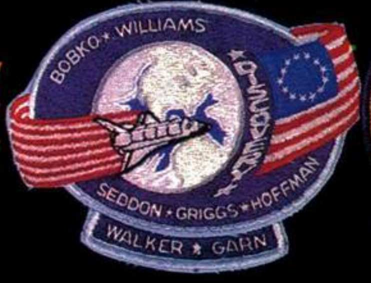
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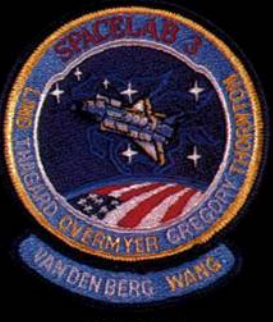
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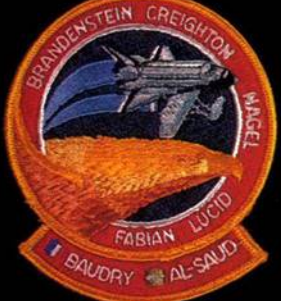
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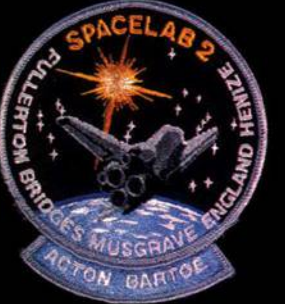
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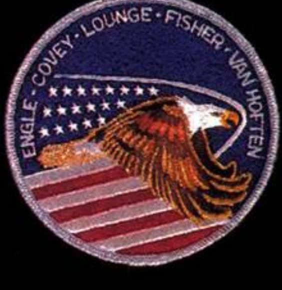
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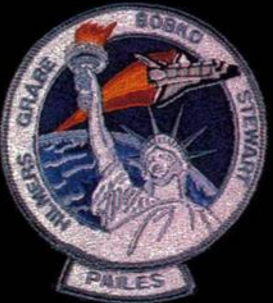
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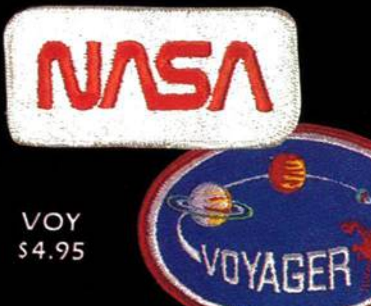
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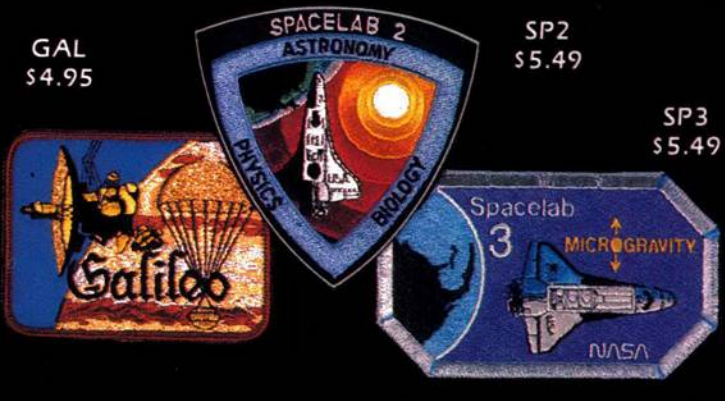
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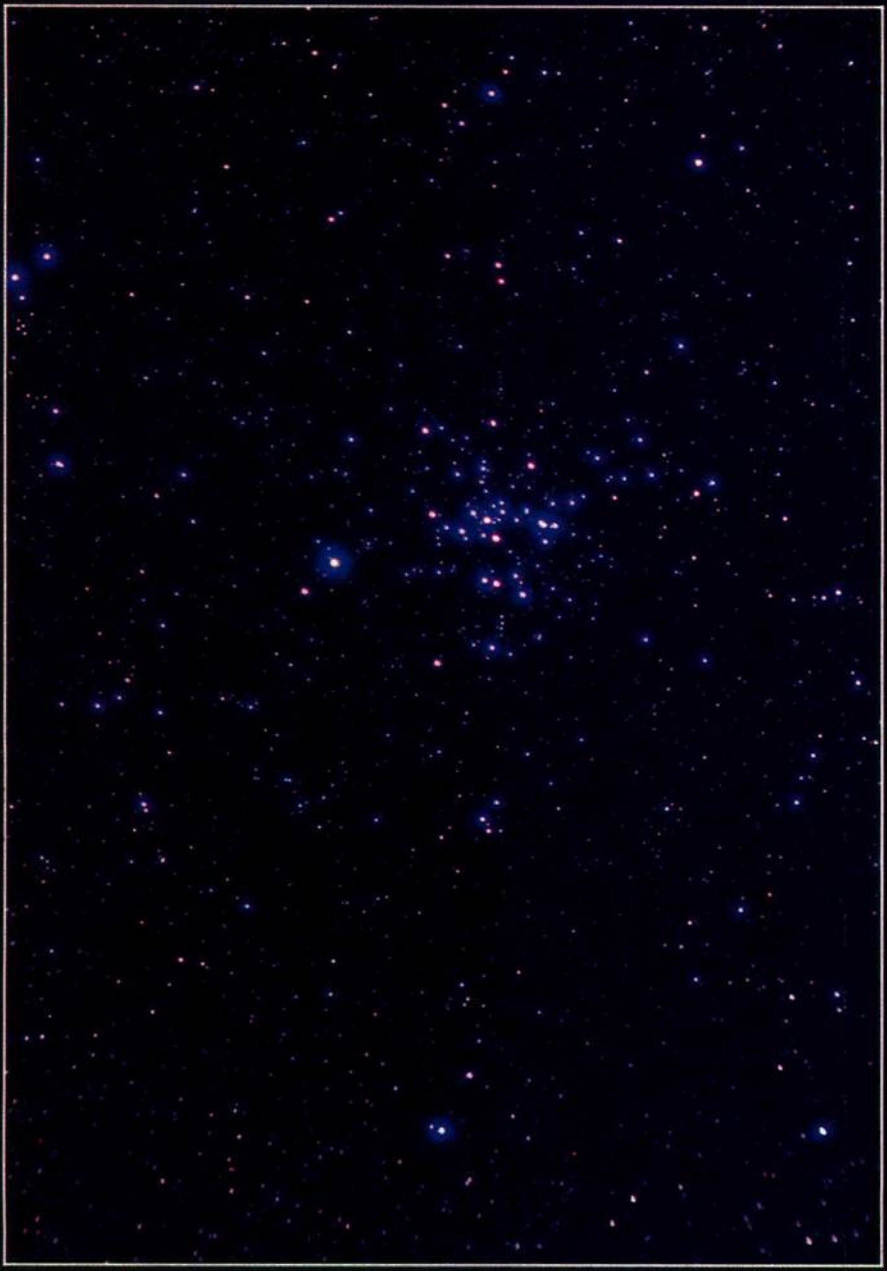


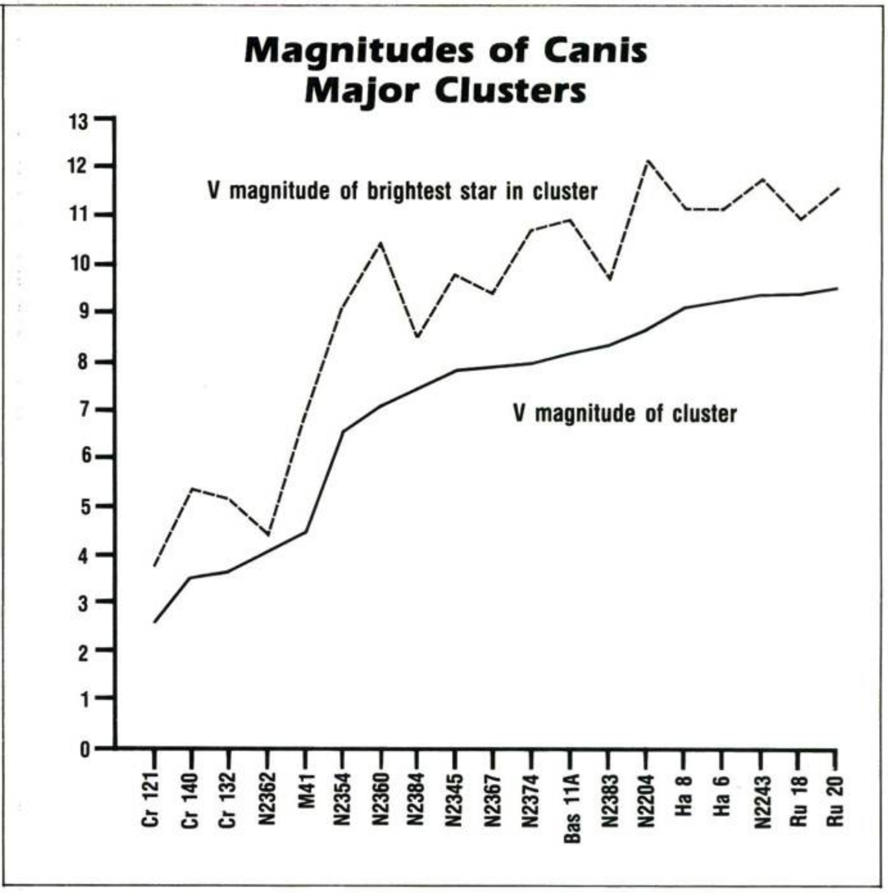
Above left: M41 is one of the winter sky's most impressive open clusters because it holds eighty members in an area measuring 80' across. Photo by Paul Maley.

Top: The 4th-magnitude open cluster NGC 2362 surrounds the star Tau Canis Majoris. Photo by Jim Barclay.

Above: NGC 2383 combines forty stars of 10th magnitude and fainter in a diameter only 6' across. Photo by Jim Barclay.

Left: Easily visible in finder scopes, NGC 2354 contains one hundred stars that combine for a magnitude of 6.5. Photo by Jim Barclay.

# Canis Major's Twenty-Six Star Clusters



**Magnitudes of Canis Major Clusters**

Of all the constellations in the sky, Canis Major is one of the best for observers of open star clusters. Twenty-six open clusters lie within the boundaries of Canis Major, ranging from naked-eye clusters to challenging sights for large backyard telescopes. Regardless of what instrument you use, each of the clusters has a unique appearance that offers a view of unknown worlds.

Because it lies just 4° south of Sirius, **M41** (NGC 2287) is one of the easiest star clusters to find in the sky. With a total magnitude of 4.5, M41 is visible to the naked eye as a small, hazy patch of light under a dark sky. Finder scopes and binoculars reveal M41's stellar nature and show a clump of several bright stars immersed in a milky nebulosity 20′ across.

Telescopes equipped with wide-field eyepieces give stunning views of M41. A 4-inch telescope at 30x shows a group of fifty mostly blue-white and orange stars scattered across an area larger than that covered by the Full Moon. An 8-inch telescope at 35x shows nearly eighty stars fainter than 7th magnitude and reveals a few yellowish and faintly reddish members. The brightest star in M41 is the magnitude 6.9 orange star near the group's center, a K3-type giant with a luminosity seven hundred times greater than that of the Sun.

Curiously, the American astronomer C. E. Barns wrote that M41 was "possibly the faintest object recorded in classical antiquity." Aristotle mentioned the fuzzy patch of light south of Sirius as far back as 325 B.C.

About 3.5° southeast of M41 lies a large, scattered group of stars called **Collinder 121**. Visible to the naked eye, this cluster of twenty stars of magnitude 3.8 and fainter has a total magnitude of 2.6. The cluster's brightest star, Omicron (ο) Canis Majoris, lies in the group; the eclipsing binary EZ Canis Majoris is located some 30′ to the north. Collinder 121 lies in a fascinating starfield to scan with binoculars. Collinder 121 and M41 both lie about 700 parsecs from Earth.

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

Six degrees east-southeast of Collinder 121 lies another of Canis Major's best clusters, **NGC 2362**. This object is also easy to find because the cluster's glow surrounds the magnitude 4.4 star Tau (τ) Canis Majoris. With a total magnitude of 4.1, NGC 2362 is visible to the naked eye, but most of the light composing the naked eye glow at this spot is from Tau and the eclipsing binary star UW Canis Majoris just 30′ to the north. You'll need a large finder scope or a 2-inch refractor to see NGC 2362's delicate splash of stars around Tau.

NGC 2362 is far smaller than M41, measuring only 8′ across. Yet within this small area lie sixty stars fainter than magnitude 7.5, most of which are white or blue-white stars. Astronomers don't know whether Tau Canis Majoris is a member of the cluster or a foreground star. NGC 2362 lies at a distance of 1.6 kiloparsecs; at this distance the Sun would appear merely as a magnitude 15.5 star. However, if Tau lies at this distance, its magnitude of 4.4 gives it a luminosity equal to 50,000 Suns.

Telescopically NGC 2362 appears as a tight, bright cluster of two dozen stars in a 4-inch telescope. An 8-inch scope at low power shows both Tau and UW Canis Majoris plus a cluster of nearly fifty stars around Tau; many of the bright members are arranged in curving lines or ellipses. Large backyard telescopes show magnificent views of NGC 2362 at moderate and high powers because of the cluster's brightness and small size. A 17.5-inch scope at 142x shows a clump of bright stars with an even sprinkling of faint ones spread throughout the field.

Lying just over 1° southwest of NGC 2362 is the large, rich cluster **NGC 2354**. This group has a total magnitude of 6.5 and contains one hundred stars of magnitudes 9.1 and fainter. Consequently, NGC 2354 is visible only as a faint, unresolved glow in binoculars. Small telescopes show NGC 2354 as a 20′-diameter collection of several dozen stars with a bright double star near the cluster's center. NGC 2354 is large enough that low powers need to be used with telescopes larger than 12 inches in aperture to show the whole group.

Three faint star clusters are arranged in a north-south line east of the NGC 2362-NGC 2354 area. One of these is **Ruprecht 18**, a 9th-magnitude group of forty stars arranged in a 4′-diameter semicircle with a bright star in the center. Two degrees north of Ruprecht 18 is the cluster **Trumpler 6**. No one has published a reliable total magnitude for this cluster, but

Trumpler 6 is visible in backyard telescopes because the group's brightest stars glow at 10th magnitude. Two degrees south of Ruprecht 18 and within the same low-power field as Eta (η) Canis Majoris is the cluster **Ruprecht 20**. Although it is slightly larger and composed of fainter stars, this cluster strongly resembles Ruprecht 18 because it has a bright central star surrounded by a circular arc of faint stars.

The extraordinarily bright clusters **Collinder 132** and **Collinder 140** lie south of this line of faint clusters in the southeastern corner of Canis Major. Shining at magnitude 3.6 and covering 95′, Collinder 132 offers a spectacular, rich starfield to binocular observers. The cluster contains only twenty-five members fainter than magnitude 5.3 in this large area, so it appears loose and sparsely populated. Collinder 140 measures about half the size of Collinder 132 but shines at nearly the same brightness. Collinder 140 is composed of thirty stars of magnitudes 5.4 and fainter and lies only 300 parsecs away.

Southwestern Canis Major contains three open star clusters. The brightest is **NGC 2243**, located 1° northeast of Lambda (λ) Canis Majoris. This cluster is a fine sight in a 6-inch or larger telescope because it contains one hundred stars fainter than magnitude 11.8 in an area only 5′ across. Large backyard telescopes show NGC 2243 as a rich knot of faint stars speckled across a nebulous haze.

Three degrees northeast of NGC 2243 is a pair of faint clusters designated **Ruprecht 2** and **Ruprecht 3**. Ruprecht 2 contains ten stars in a 7′-diameter; the brightest shine at 12th magnitude. Ruprecht 3 spans half as much sky but contains fifteen stars of magnitudes 11 and fainter.

The area of Canis Major east of M41 contains a number of open clusters. **Ruprecht 11**, 5° east of M41, appears much like Ruprecht 3. It contains twenty stars of 11th magnitude and fainter in a 2.9′ diameter. Four degrees east of this cluster lies a pair of star groups. **NGC 2383** is a magnitude 8.4 cluster composed of forty 10th-magnitude and fainter stars. A 6-inch telescope shows this group as a compressed cluster containing a dozen bright stars and many fainter ones. Just southwest of NGC 2383 is **Haffner 8**, a 9th-magnitude group of stars covering only 4.2′.

Two degrees north of the NGC 2383-Haffner 8 pair lies **Ruprecht 16**, a cluster of fifteen faint stars arranged in a slightly flattened triangle. This cluster is unimpressive in anything less than a 10-inch or 12-inch telescope, but a large telescope under a dark sky shows Ruprecht 16 as a good, representative star cluster that evaded inclusion in the *New General Catalogue* and *Index Catalogue*.

Six open clusters are located in the northeastern corner of Canis Major. **NGC 2360** lies 4° north of Ruprecht 16 within the same low-power field as a 5th-magnitude star. This 7th-magnitude cluster contains eighty stars fainter than 10th magnitude in an area 13′ across, which makes it impressive when viewed with even the smallest telescopes. Just over 1° to the northeast lie **Basel 11A** and **Haffner 6**, two reasonably bright clusters visible in 6-inch telescopes on a good night. One degree northeast of the Basel 11A-Haffner 6 pair is the 8th-magnitude cluster **NGC 2374**, a group of forty 10th-magnitude and fainter stars packed into a 6′ diameter. **NGC 2345** is a rich group of 10th-magnitude and fainter stars located 3° northwest of Basel 11A. Three and one-half degrees south of NGC 2345 is the cluster **Haffner 23**, a very faint group that may prove elusive to all but large backyard instruments.

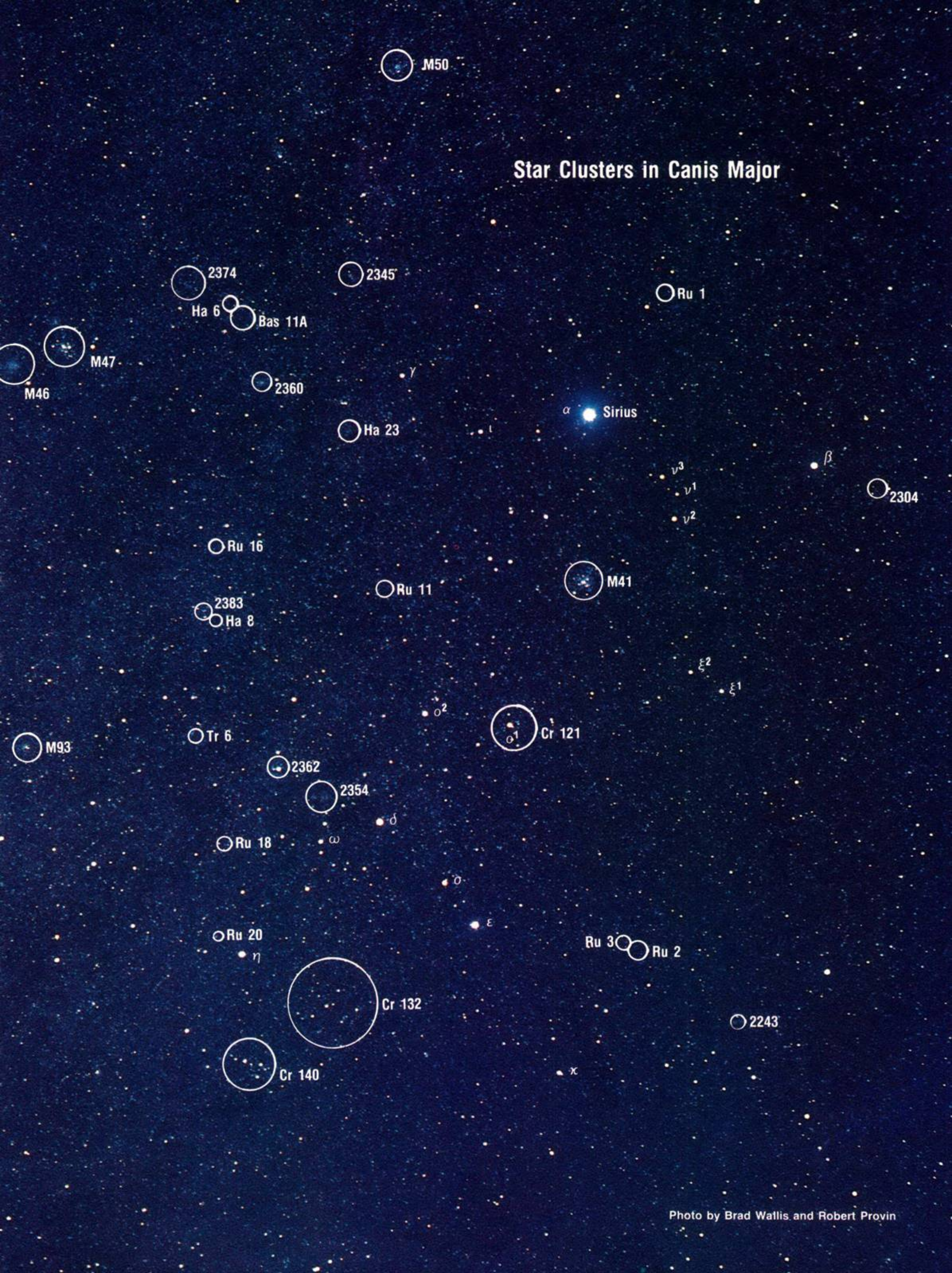
**Ruprecht 1** can be found by sweeping just over 3° northwest of Sirius. However, don't stare at Sirius first or you may not spot the cluster, which glows faintly from the light of fifteen 11th-magnitude stars spread over 11′. This cluster is more of a challenge to find rather than a pretty sight once you find it. The group's fifteen stars are shaped into an arrow that somewhat resembles the constellation Sagitta.

On the western side of Canis Major is **NGC 2204**, a rich cluster of faint stars that together glow with the light of a single, magnitude 8.6 star. This group is easily visible in a 3-inch telescope and appears as a nebulous knot peppered with pinpoint specks of glistening light.

*— David J. Eicher*

## Open Star Clusters in Canis Major

| Object | R.A. (2000.0) | Dec. | Mag. | Mag.★ | N | Size | Distance | Diameter |
|---|---|---|---|---|---|---|---|---|
| NGC 2204 | 6h 15.7m | −18°39′ | 8.6 | 12.2 | 80 | 13′ | 4.5 kpc | 17 pc |
| NGC 2243 | 6h 29.8m | −31°17′ | 9.4 | 11.8 | 100 | 5′ | 4.6 kpc | 7 pc |
| Ruprecht 1 | 6h 36.4m | −14°11′ | — | 11p | 15 | 11′ | — | — |
| Ruprecht 2 | 6h 41.0m | −29°33′ | — | 12p | 10 | 7′ | — | — |
| Ruprecht 3 | 6h 42.1m | −29°27′ | — | 11p | 15 | 2.8′ | — | — |
| M41 (NGC 2287) | 6h 47.0m | −20°44′ | 4.5 | 6.9 | 80 | 38′ | 700 pc | 8 pc |
| Collinder 121 | 6h 54.2m | −24°38′ | 2.6 | 3.8 | 20 | 50′ | 700 pc | 10 pc |
| Ruprecht 11 | 7h 07.4m | −20°48′ | — | 11p | 20 | 2.9′ | — | — |
| NGC 2345 | 7h 08.3m | −13°10′ | 7.7 | 9.9 | 70 | 12′ | 1.8 kpc | 6 pc |
| Haffner 23 | 7h 09.4m | −16°57′ | — | 13p | 40 | 11′ | — | — |
| NGC 2354 | 7h 14.3m | −25°44′ | 6.5 | 9.1 | 100 | 20′ | 1.9 kpc | 11 pc |
| Collinder 132 | 7h 14.4m | −31°10′ | 3.6 | 5.3 | 25 | 95′ | — | — |
| Basel 11A | 7h 17.1m | −13°58′ | 8.2 | 10.9 | 30 | 9′ | 1.5 kpc | 4 pc |
| NGC 2360 | 7h 17.8m | −15°37′ | 7.2 | 10.4 | 80 | 13′ | 1.6 kpc | 6 pc |
| NGC 2362 | 7h 18.8m | −24°57′ | 4.1 | 4.4 | 60 | 8′ | 1.6 kpc | 4 pc |
| Haffner 6 | 7h 20.1m | −13°08′ | 9.2 | 11.1 | 60 | 4.0′ | 1.1 kpc | 1.2 pc |
| NGC 2367 | 7h 20.1m | −21°56′ | 7.9 | 9.4 | 20 | 3.5′ | 2.0 kpc | 2 pc |
| Ruprecht 16 | 7h 23.2m | −19°27′ | — | 13p | 15 | 11′ | — | — |
| Haffner 8 | 7h 23.4m | −21°02′ | 9.1 | 11.1 | 30 | 4.2′ | 1.7 kpc | 2 pc |
| Collinder 140 | 7h 23.9m | −32°12′ | 3.5 | 5.4 | 30 | 42′ | 300 pc | 4 pc |
| NGC 2374 | 7h 24.0m | −13°16′ | 8.0 | 10.8 | 25 | 19′ | 1.3 kpc | 7 pc |
| NGC 2383 | 7h 24.8m | −20°56′ | 8.4: | 9.8 | 40 | 6′ | 2.0 kpc | 4 pc |
| Ruprecht 18 | 7h 24.8m | −26°13′ | 9.4 | 11.0 | 40 | 4.0′ | — | — |
| NGC 2384 | 7h 25.1m | −21°02′ | 7.4: | 8.6 | 15 | 2.5′ | 2.0 kpc | 1.5 pc |
| Trumpler 6 | 7h 26.1m | −24°18′ | — | 10.0p | — | 6′ | — | — |
| Ruprecht 20 | 7h 26.7m | −28°53′ | 9.5 | 11.6 | 30 | 10′ | — | — |

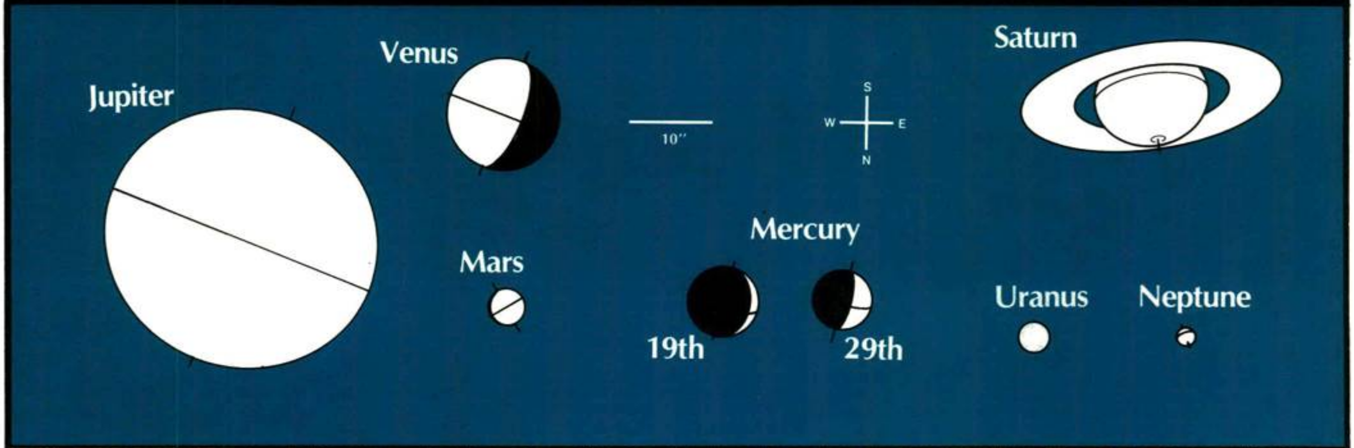


Star Clusters in Canis Major

M50
2374
2345
Ru 1
Ha 6
Bas 11A
M47
M46
2360
γ
α
Sirius
Ha 23
ι
β
ν3
ν1
ν2
2304
Ru 16
Ru 11
M41
2383
Ha 8
ξ2
ξ1
o2
Cr 121
o1
M93
Tr 6
2362
2354
δ
Ru 18
ω
σ
ε
Ru 20
Ru 3
Ru 2
η
Cr 132
2243
Cr 140
κ

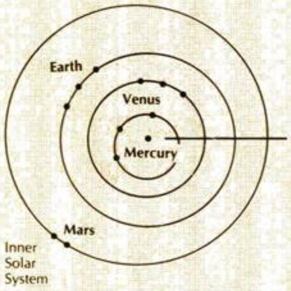
Photo by Brad Wallis and Robert Provin

# Planetary Data February 1988

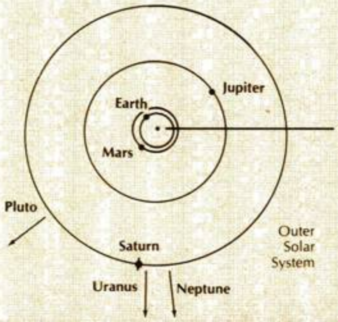


Jupiter
Venus
10''
S
W
E
N
Saturn
Mars
Mercury
19th
29th
Uranus
Neptune

|  |  | Date | Mag. | Angular Size | % Illum. | Distance (AU) from: Earth | Distance (AU) from: Sun | Longitude: Heliocentric | Ecliptic | R.A. (2000.0) | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sun** |  | 1 | −26.8 | 32.5′ | — | 0.985 | — | — | 311°20.4′ | 20h 55.8m | −17°36.7′ |
|  |  | 15 | −26.8 | 32.4′ | — | 0.988 | — | — | 325°31.2′ | 21h 51.8m | −12°57.7′ |
|  |  | 29 | −26.8 | 32.3′ | — | 0.991 | — | — | 339°37.5′ | 22h 45.3m | −7°54.1′ |
| **Mercury** | ☿ | 1 | 0.3 | 8.2″ | 31% | 0.821 | 0.308 | 81°35.3′ | 327°32.9′ | 21h 59.0m | −10°47.0′ |
|  |  | 15 | 3.2 | 10.4″ | 5% | 0.648 | 0.362 | 160°25.3′ | 317°40.2′ | 21h 15.2m | −12°09.2′ |
|  |  | 29 | 0.4 | 8.3″ | 41% | 0.812 | 0.435 | 213°14.3′ | 314°15.6′ | 21h 05.8m | −15°37.3′ |
| **Venus** | ♀ | 1 | −4.1 | 14.5″ | 77% | 1.154 | 0.723 | 47°48.9′ | 349°57.2′ | 23h 24.7m | −4°55.2′ |
|  |  | 15 | −4.1 | 15.7″ | 72% | 1.064 | 0.721 | 70°18.4′ | 6°36.0′ | 0h 24.7m | 2°23.8′ |
|  |  | 29 | −4.2 | 17.3″ | 67% | 0.967 | 0.719 | 92°53.7′ | 22°52.9′ | 1h 23.6m | 9°33.4′ |
| **Mars** | ♂ | 10 | 1.3 | 5.2″ | 92% | 1.814 | 1.553 | 228°43.3′ | 261°48.6′ | 17h 24.3m | −23°10.1′ |
|  |  | 20 | 1.2 | 5.4″ | 91% | 1.729 | 1.540 | 233°46.9′ | 268°32.3′ | 17h 53.6m | −23°33.5′ |
| **Jupiter** | ♃ | 15 | −2.2 | 36.6″ | 99% | 5.384 | 4.966 | 35°35.0′ | 25°50.4′ | 1h 37.3m | 8°57.6′ |
| **Saturn** | ♄ | 15 | 0.6 | 15.7″ | 100% | 10.568 | 10.041 | 265°26.5′ | 270°14.5′ | 18h 01.1m | −22°19.8′ |
| **Uranus** | ⛢ | 15 | 5.7 | 3.5″ | 100% | 19.799 | 19.257 | 267°34.8′ | 270°05.7′ | 18h 00.7m | −23°37.2′ |
| **Neptune** | ♆ | 15 | 8.0 | 2.2″ | 100% | 30.903 | 30.228 | 277°59.8′ | 279°28.1′ | 18h 41.1m | −22°08.7′ |
| **Pluto** | ♇ | 15 | 13.7 | 0.1″ | 100% | 29.443 | 29.671 | 220°38.9′ | 222°41.5′ | 15h 00.7m | −0°09.0′ |



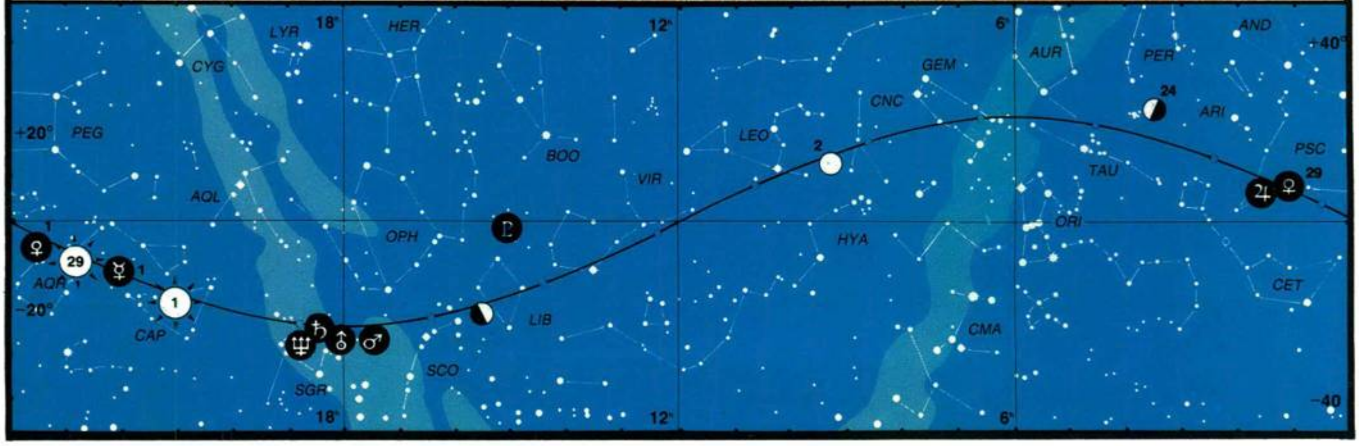
Earth
Venus
Mercury
Mars
Inner Solar System



Jupiter
Earth
Mars
Pluto
Saturn
Uranus
Neptune
Outer Solar System

## Moon Data

|  |  |
|---|---|
| Full Moon | Feb. 2 at 20h51m |
| Last Quarter | Feb. 10 at 23h01m |
| New Moon | Feb. 17 at 15h54m |
| First Quarter | Feb. 24 at 12h15m |
| Full Moon | March 3 at 16h01m |
| Last Quarter | March 11 at 10h56m |
| Apogee: Feb. 3 at 10h29m | 406,395 km |
| Perigee: Feb. 17 at 9h43m | 356,914 km |



LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
AUR
PER
24
CNC
ARI
+20°
PEG
LEO
2
BOO
VIR
PSC
TAU
29
AQL
ORI
OPH
HYA
29
1
1
AQR
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LIB
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SCO
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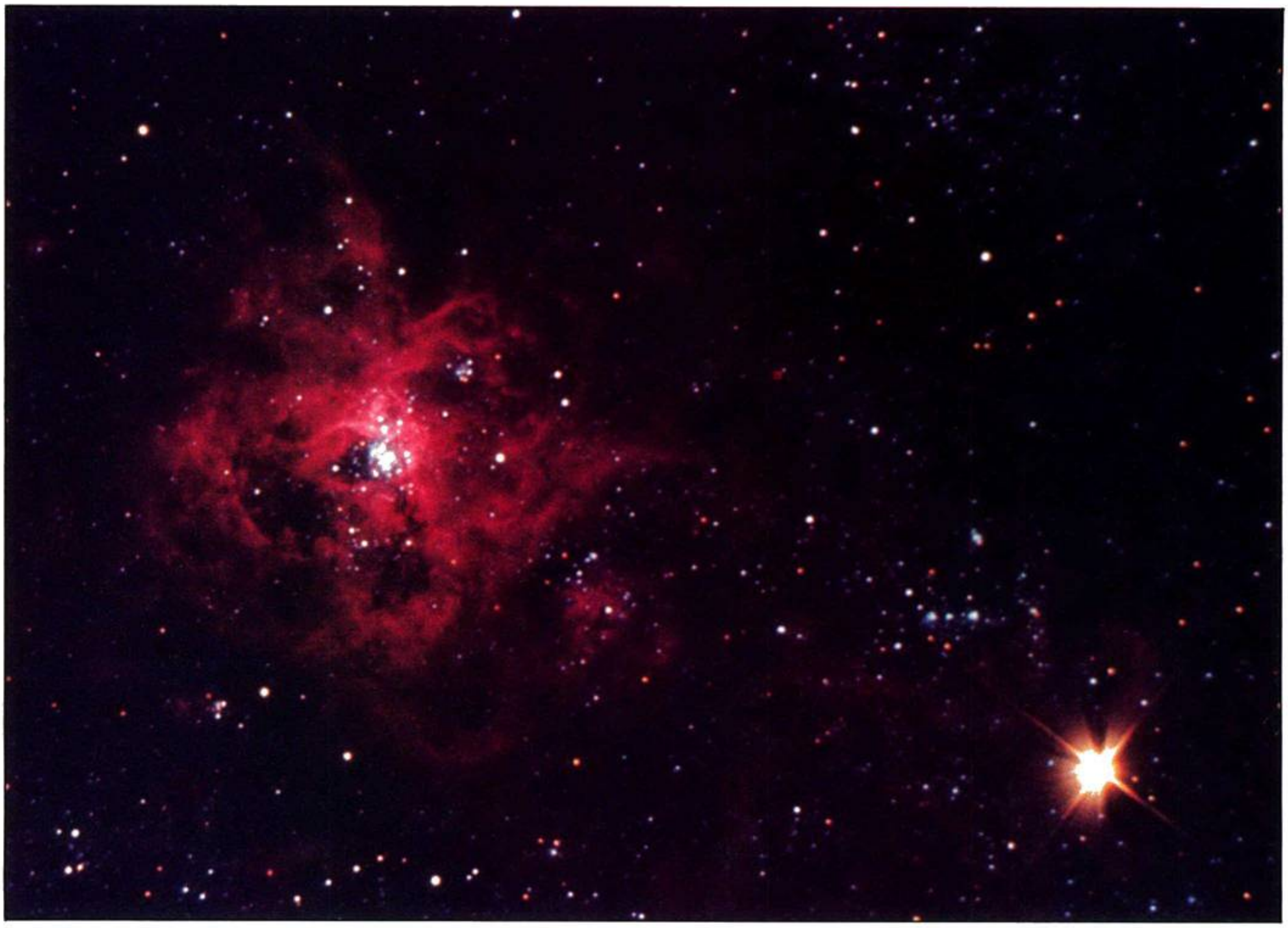
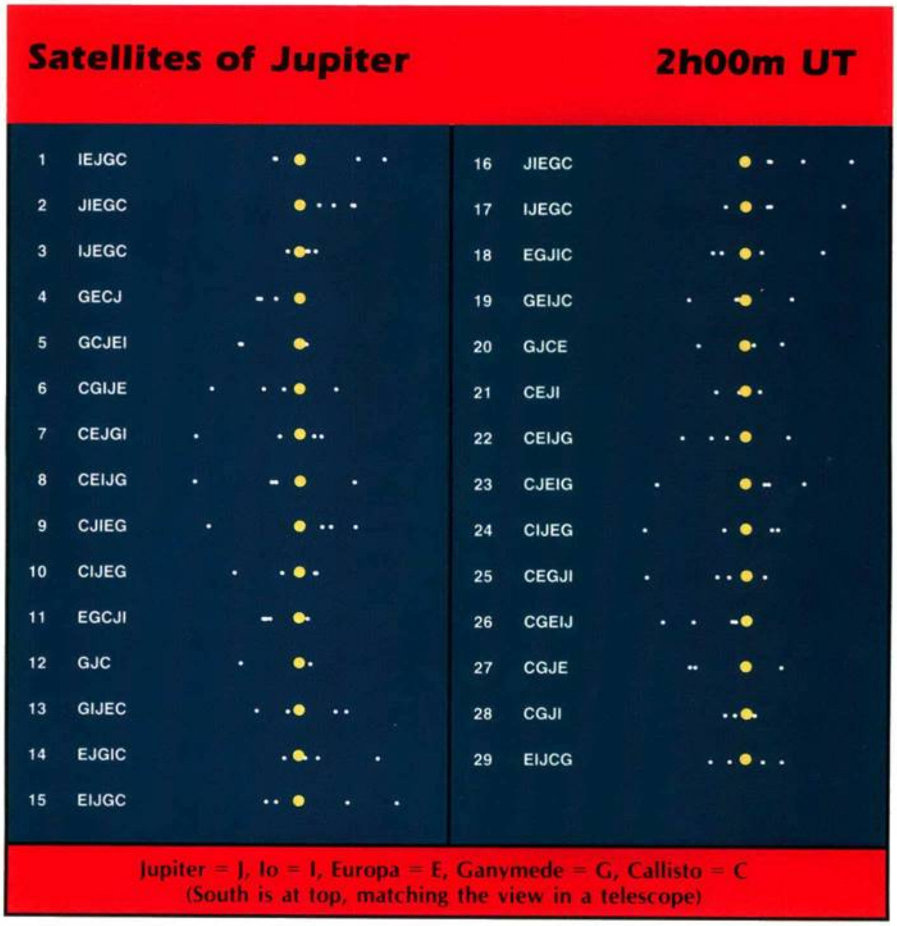
18h
12h
6h
−40



**Southern Hemisphere observers kept their eyes on Supernova 1987A in the Large Magellanic Cloud last year, and because of its proximity to the Tarantula Nebula, the supernova was easy to identify. On April 6, when this photo was taken, the supernova shone at magnitude 3.7. Photo by Noel Munford, who used a 12-inch f/7 reflector, hypersensitized Fujichrome 100 film, and a 30-minute exposure.**



## Planets

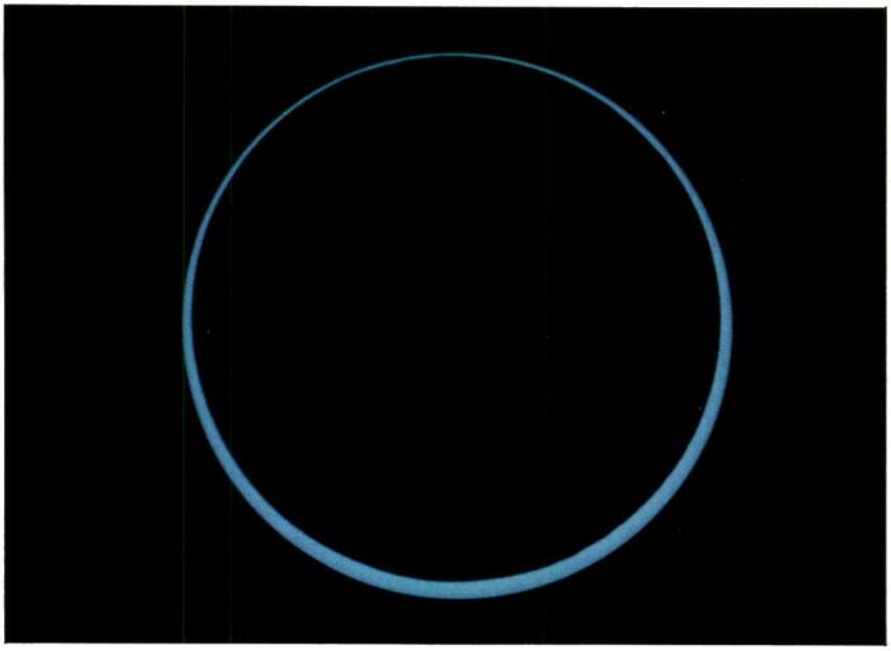
### Mercury

After moving through inferior conjunction on February 11, Mercury swiftly rises into visibility in the predawn sky. About a week after conjunction you can spot it very low in the east-southeast this month. Mercury's peak elevation of 4° comes forty-five minutes before sunrise on the 29th. Thereafter Mercury dips steadily lower, vanishing around March 20. The planet's greatest elongation from the Sun, a distance of 27°, occurs on March 8.

Viewing any planet while it is at a low elevation poses difficulties because of the atmosphere's unsteadiness. The most fruitful approach is to locate Mercury while it is low and the sky is relatively dark. Then, while dawn brightens, observe the planet as it rises higher and the seeing becomes steadier.

### Venus

High and bright in the southwest after



sunset, Venus is hard not to see. Moderate magnifications (100x to 200x) reveal that Venus' disk is distinctly gibbous — like a featureless Moon a few days after First Quarter. If the glare is dazzling, locate Venus earlier and start viewing it while the sky is bright with twilight.

### Mars

Holding a fairly fixed position in the predawn sky, Mars is an easy object to find. By itself, Mars is slowly becoming more interesting as its apparent size grows steadily until September. On February 15, however, its diameter is only 5.3".

But Mars is also interesting this month because of its conjunctions with Uranus (on the 22nd) and Saturn (on the 23rd). The Mars-Uranus conjunction occurs at 20h49m UT (late afternoon for easterners, early afternoon on the West Coast), when the centers of both planets will lie 40" apart with Mars to the north. But because they both lie below the horizon at that time of day, you will have to observe the two planets before conjunction on the morning of the 22nd or (better yet) after conjunction on the 23rd.

Mars' conjunction with Saturn occurs at 12h43m UT on the 23rd when the two planets will be 1°18′ apart. Because the event occurs in the predawn hours, the 23rd offers your best chances of seeing Uranus, Saturn, and Mars closely grouped — weather permitting, of course. Use low magnification to pull all three into the same field of view.

### Minor Planets

1 Ceres is in conjunction with the Sun on February 1 and is invisible all month.

2 Pallas (magnitude 10.4) is moving eastward through central Aquila where at the end of February it lies about 2-1/2° southwest of Altair. Its positions:

| | | |
|---|---|---|
| 1st: | 19h12m35s, | 4°11.6′ |
| 10th: | 19h24m24s, | 4°46.2′ |
| 20th: | 19h37m01s, | 5°32.5′ |
| 29th: | 19h47m50s, | 6°20.4′ |

**On September 23, 1987, observers in the Soviet Union, the south Pacific, and Australia witnessed an annular eclipse of the Sun. Lawrence M. Cooper photographed the event at mid-eclipse from Okinawa with an 8-inch f/10 SCT, ISO 400 film, a mylar filter fitted over the telescope, and a 1/500-second exposure.**

**Chris Schur's photograph of the Omega Nebula in Sagittarius nets him this month's $100 "Best Astrophoto" award. Chris used a 16-inch f/4.5 telescope fitted with a Deep Sky filter, hypersensitized Konica SR 1600 film, and a 30-minute exposure.**

Pallas rises around 4 a.m. local time on the 15th.

3 Juno (9.7) lies in northern Cetus near its border with Pisces and Aquarius. Juno's positions:

| | | |
|---|---|---|
| 1st: | 0h02m24s, | −5°09.5′ |
| 10th: | 0h20m04s, | −3°37.6′ |
| 20th: | 0h40m12s, | −1°51.6′ |
| 29th: | 0h58m45s, | −0°14.1′ |

Juno sets about 8:30 local time on the 15th.

4 Vesta (6.8) is moving retrograde (westward) in eastern Gemini. Late in the month, it passes about 2° south of 1st-magnitude Pollux. Its positions:

| | | |
|---|---|---|
| 1st: | 8h08m17s, | 24°16.3′ |
| 10th: | 7h59m29s, | 25°01.3′ |
| 20th: | 7h51m46s, | 25°38.3′ |
| 29th: | 7h47m21s, | 25°59.6′ |

Because it came to opposition late last month, Vesta is visible all night.

To locate a minor planet, photocopy the appropriate chart from a good star atlas (*Uranometria 2000.0*, for example, or *Sky Atlas 2000.0*), plot the object's dated positions lightly in pencil, and sketch a smooth curve linking the points. (Positions are in epoch 2000.0 coordinates for 0h UT.) Then observe the starfield at low magnification and photograph or plot by hand what you see. Recheck the field a night or two later; the "star" that moved is the minor planet.

### Jupiter

Like Venus (though much dimmer), Jupiter is a prominent object in the southwestern sky after sunset. This month and next offer the last good chances to view the giant planet before it sinks too low.

On the 1st, Jupiter spans 38" across its equator (36" over the poles) and by the 29th these measurements will be down to 35" and 33" respectively. To bring out

details in its many cloud belts, try observing with colored photo filters such as a Wratten 25 (strong red) or 82A (light blue). When working without filters, many observers prefer to view during twilight.

### Saturn

On February 13 at 0h34m UT, Saturn will pass 1°17′ north of Uranus. At the time of conjunction they are below the horizon for North American viewers. (It is early evening on the 12th for the East Coast and late afternoon in the west.) Yet the two will still be close when they rise together in the predawn hours of the 13th.

See above under Mars for details of Saturn's conjunction with Mars.

### Uranus

This month Uranus has two fine conjunctions: with Saturn on the 13th and with Mars on the 22nd. (See under Mars and Saturn for details.)

### Neptune

Neptune is still relatively low in the southeastern sky as morning twilight begins. Use the finder chart in the January issue to locate it. Neptune has a grayish disk, 2.2″ across, at 8th magnitude.

### Pluto

Requiring a 10- to 12-inch telescope to be seen, Pluto poses a definite viewing challenge. It shines at 13.8 magnitude, identical with thousands of stars. The finder chart in the January issue will get you into the correct region of sky. Then follow the procedure for locating a minor planet: map the field one night and look for the object that has moved when you reobserve the field a night or two later.

— *Robert Burnham*

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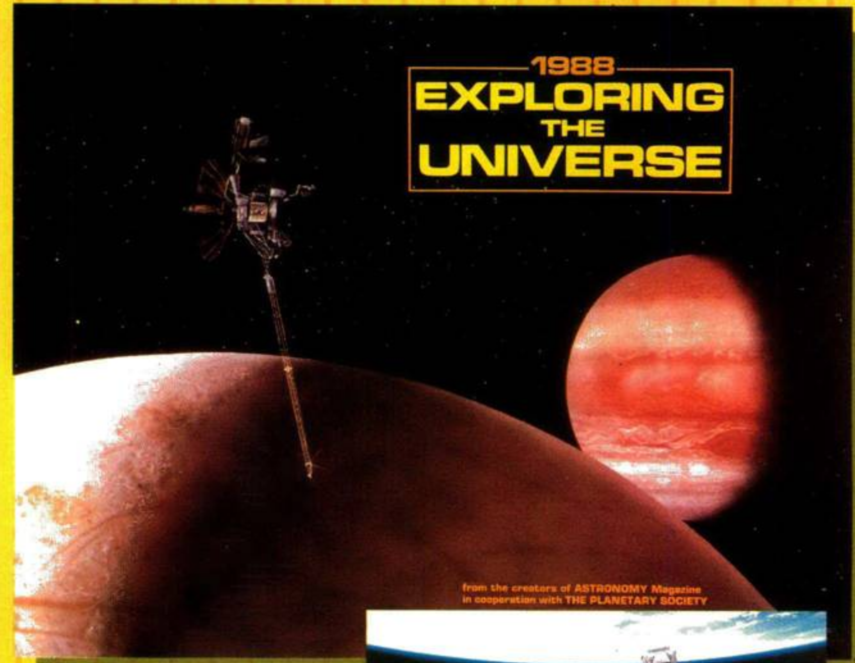
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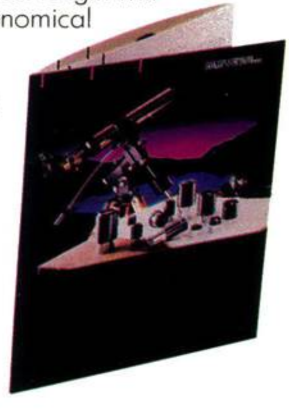

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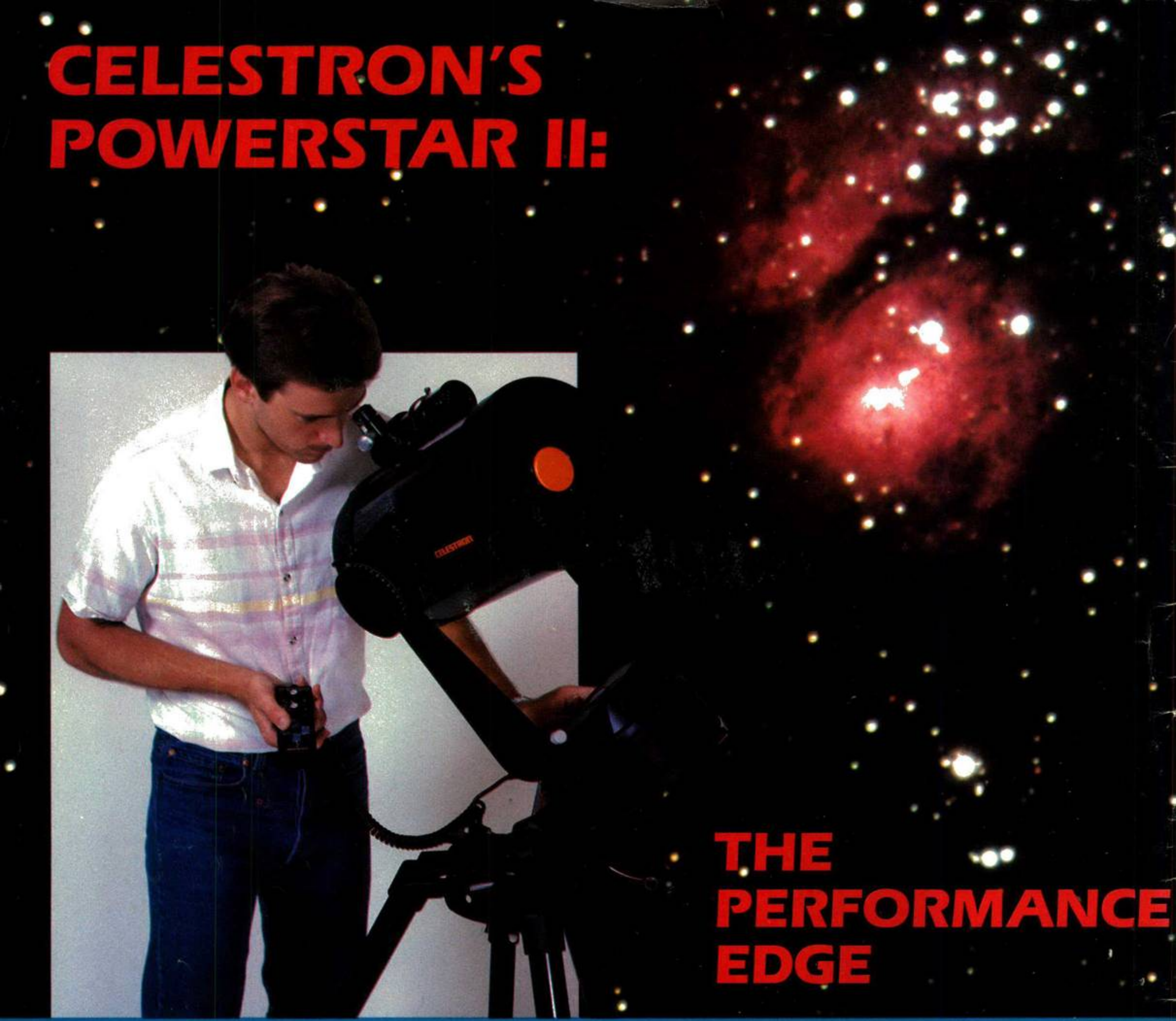

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